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THE MEASUREMENT OF MICROWAVE MULTIPATH IN AN AIRPORT ENVIRONMENT

R.W. Hubbard

L.E. Pratt

W.J. Hartman

January 1977

Final Report

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
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This report presents the results of multipath measurements made on a) airport terminal buildings, 2) large maintenance hangars, and 3) aircraft on the surface of the airport. Results indicate that significant reflection levels are prevalent from these sources, and could produce a multipath reception problem at the receiver of an aircraft approaching the runway.

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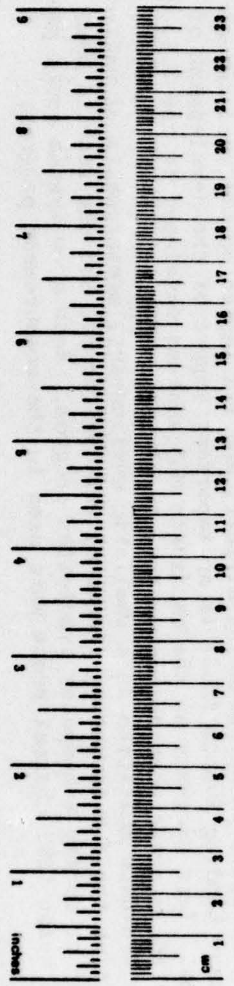
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

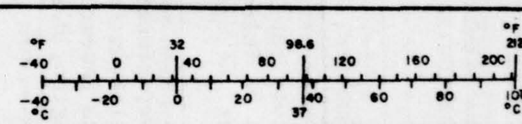
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



FEDERAL AVIATION ADMINISTRATION
SYSTEMS RESEARCH AND DEVELOPMENT SERVICE
SPECTRUM MANAGEMENT STAFF

STATEMENT OF MISSION

The mission of the Spectrum Management Staff is to assist the Department of State, Office of Telecommunications Policy, and the Federal Communications Commission in assuring the FAA's and the nation's aviation interests with sufficient protected electromagnetic telecommunications resources throughout the world to provide for the safe conduct of aeronautical flight by fostering effective and efficient use of a natural resource - the electromagnetic radio frequency spectrum.

This objective is achieved through the following services:

- Planning and defending the acquisition and retention of sufficient radio frequency spectrum to support the aeronautical interests of the nation, at home and abroad, and spectrum standardization for the world's aviation community.

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- Conducting electromagnetic compatibility analyses to determine intra/inter-system viability and design parameters, to assure certification of adequate spectrum to support system operational use and projected growth patterns, to defend aeronautical services spectrum from encroachment by others, and to provide for the efficient use of the aeronautical spectrum.

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- Providing spectrum management consultation, assistance, and guidance to all aviation interests, users, and providers of equipment and services, both national and international.

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THE MEASUREMENT OF MICROWAVE MULTIPATH IN AN AIRPORT ENVIRONMENT

R.W. Hubbard
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W.J. Hartman*

Multipath in an operating airport, and its impact on the performance of a Microwave Landing System (MLS) is an important aspect of the development of these systems. Test programs on the candidate MLS systems developed in the U.S. were conducted in areas that do not emulate large commercial airports. In order to better evaluate multipath in a realistic environment, measurements of reflected signals at the MLS operating frequency were performed, and the results used to develop or modify a computer simulation program. Both a cw system and a pseudo-random noise (PN) channel probe were used in the measurement program.

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Key Words: Multipath, microwave landing system, pseudo-random noise, impulse response, time-delay, and channel probe.

1. INTRODUCTION

The U.S. Department of Transportation (DoT), under the direction of the Federal Aviation Administration (FAA), has been conducting a development program for a Microwave Landing

*The authors are with the Institute for Telecommunication Sciences, Office of Telecommunications, U.S. Department of Commerce, Boulder, Colorado 80302.

System (MLS). The system is to eventually replace the Instrument Landing System (ILS) that is in general use in both the U.S. and around the world. As a part of the national plan for development, the Microwave Landing System Phase II Test Program was specified and conducted to test several candidate MLS systems. As a part of the supporting activity to the test program, the Massachusetts Institute of Technology Lincoln Laboratories (MITLL) was under contract to the FAA to develop certain computer models to evaluate MLS performance under simulated conditions. This modeling effort included consideration of the potential multipath environment at a major airport that could seriously impare the accuracy and general performance of the MLS. Little quantitative information was available on either the magnitude or character (specular, dispersive) of this multipath at microwave frequencies. The effects of assumed multipath had been studied earlier in a discrete mode (Guarino, 1975) and in a dynamic mode (Wightman, et al., 1973). Both of these studies were based on simulation processes. Multipath consideration also formed a part of the MLS Phase II Test Program (DoT/FAA, 1973a), in which specific screen reflectors were used in various orientations during actual test procedures.

In support of the modeling work of MITLL, the Office of Telecommunications, Institute for Telecommunication Sciences (OT/ITS) was asked to perform some actual measurements in an airport environment to determine the characteristics of the multipath at the MLS operating frequency. A cooperative experiment was planned by OT/ITS and MITLL, and conducted with support of the FAA. This report describes the experiment, the instrumentation used, and the basic results of the measurements. The final results have been used by the MITLL investigators to confirm or revise the estimates and characterizations used in their computer modeling work (Shnidman, 1975). It is beyond the scope of this report to discuss in any detail the modeling application of the experiment results. The reader is referred to the above reference for these details.

Preliminary measurements were performed at the FAA National Aviation Facilities Evaluation Center (NAFEC) near Atlantic City, New Jersey. Tests there were primarily for the purpose of installing and checking out test equipment and operational

equipment and operational facilities, and to perform a few specific measurements on the reflective screens used in the MLS Phase II Test Program conducted at NAFEC. Later, the experiment equipment was moved to Logan International Airport in Boston, Massachusetts where measurements were made in an operational airport environment. Logan International Airport is operated by the Massport Authority, and all of the necessary coordination for the experiment was conducted with officials of Massport by personnel from MITLL. The actual measurements were arranged for in cooperation with the Massport officials and the FAA traffic controllers. The availability of areas within the airport for the experiment were dictated from normal operating procedures, and were conducted to satisfy the requirements developed by the MITLL staff.

2. MEASUREMENT SYSTEMS

2.1 Microwave Equipment

The experiment equipment consisted of two microwave systems; the first was a cw transmitter and receiver operating at 4.035 GHz, and the second a channel probe system operating at 5.10 GHz. The cw system was used as a continuous monitor of the received signal level (RSL) in all measurements, and thus to describe the combined signal character of any multipath situation and to dictate specific measurements to be performed with the channel probe. The cw system is shown in block diagram form in figure 1. All components in the system are solid state, including the final power amplifier stage of the transmitter. A log-linear amplifier is used in the receiver to provide a logarithmic RSL calibration and consequently a wide dynamic range (~60dB). The RSL was recorded on both a strip chart and magnetic tape. Calibrations were performed primarily in a relative manner, using the received signal as a source for the receiver in any given, fixed position (see the details in sections 3 and 4). A calibrated precision attenuator was used in the receiver antenna line to calibrate the operating range.

The channel probe system used to evaluate the multipath components was designed at OT/ITS to perform impulse response measurements in radio transmission channels. It is based on the convolution model as (Linfield, et al., 1976):

$$y(t) = h(t) \otimes x(t) \tag{1}$$

where $y(t)$ is the output signal, $x(t)$ is the input signal, $h(t)$ is the impulse response of the channel, and $\otimes$ denotes the convolution integral.

In (1), if the input signal is a sharp impulse function then the convolution with $h(t)$ yields a $y(t)$ that is equal to $h(t)$. This is a property of convolution with an impulse; the result is the convolved function function located at the position of the impulse (Lee, 1960). Applying this technique directly requires that the test signal be a delta-like impulse at an appropriate carrier frequency, with an associated wide bandwidth required in both transmitter and receiver. Also, the peak power requirements would be high in order to obtain a good

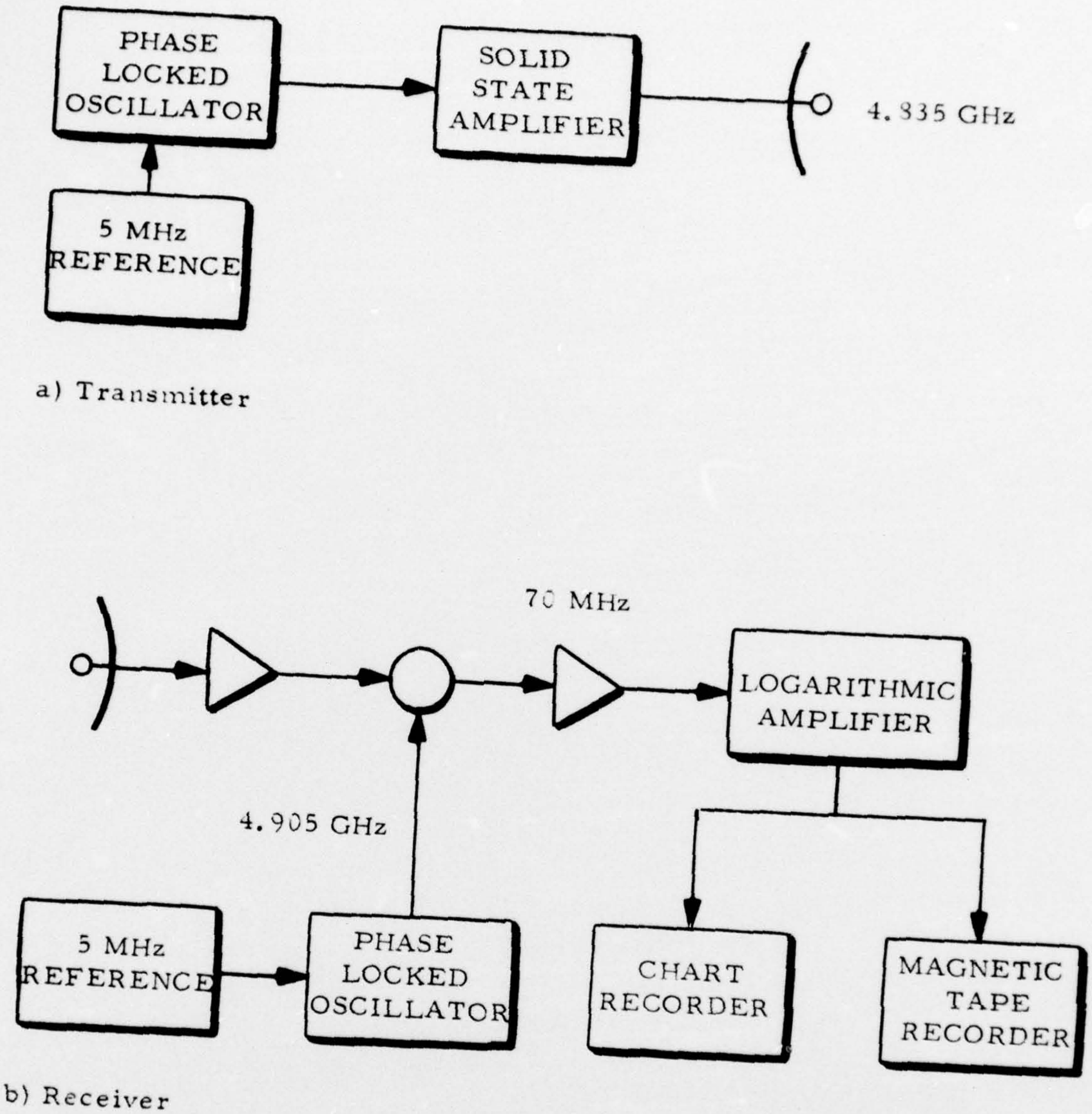

Figure 1. Block diagram of the 4.835 GHz cw system.

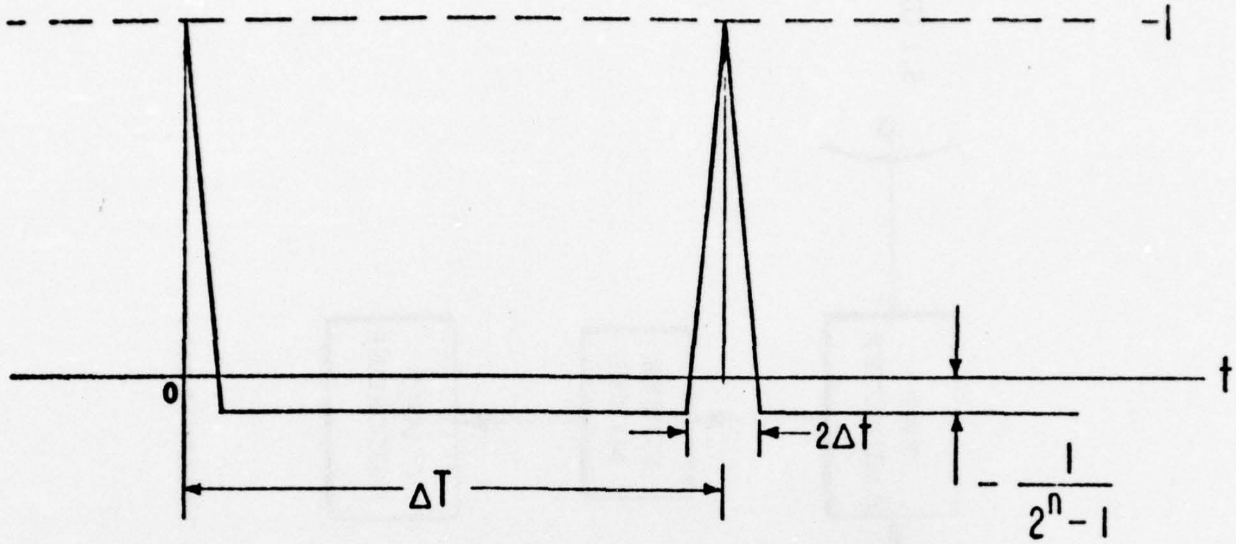

Figure 2. Illustration of the autocorrelation function for a PN binary sequence of maximal length.

channel response and a multipath component is one bit time, or 6.67 ns. However, it is possible to resolve multipath components with delay time less than this value, down to the order of 1 ns. This feature will be discussed later in the report.

The block diagram of the PN probe transmitter is shown in figure 3. Note that all operating frequencies, including the PN clock rate, the 600 MHz IF, and the microwave carrier are derived from a common stable reference oscillator at 5 MHz. Translation of the PN code to the microwave carrier is accomplished as a bi-phase modulation of the 600 MHz IF. The latter signal is then mixed with 4.5 GHz, yielding two sidebands at 3.9 GHz and 5.1 GHz. The lower sideband is removed by the bandpass filter in the transmitter, and only the upper sideband is passed for transmission. The final power amplifier is a traveling wave tube (TWT) capable of up to 20 watts output.

The cw and PN probe signals were multiplexed to a common antenna at the transmitter terminal for all measurements. A waveguide tee and ferrile isolators were used for this purpose as shown in figure 4.

The PN probe receiver system is shown in block diagram form in figure 5. As in the transmitter, all frequencies of operation

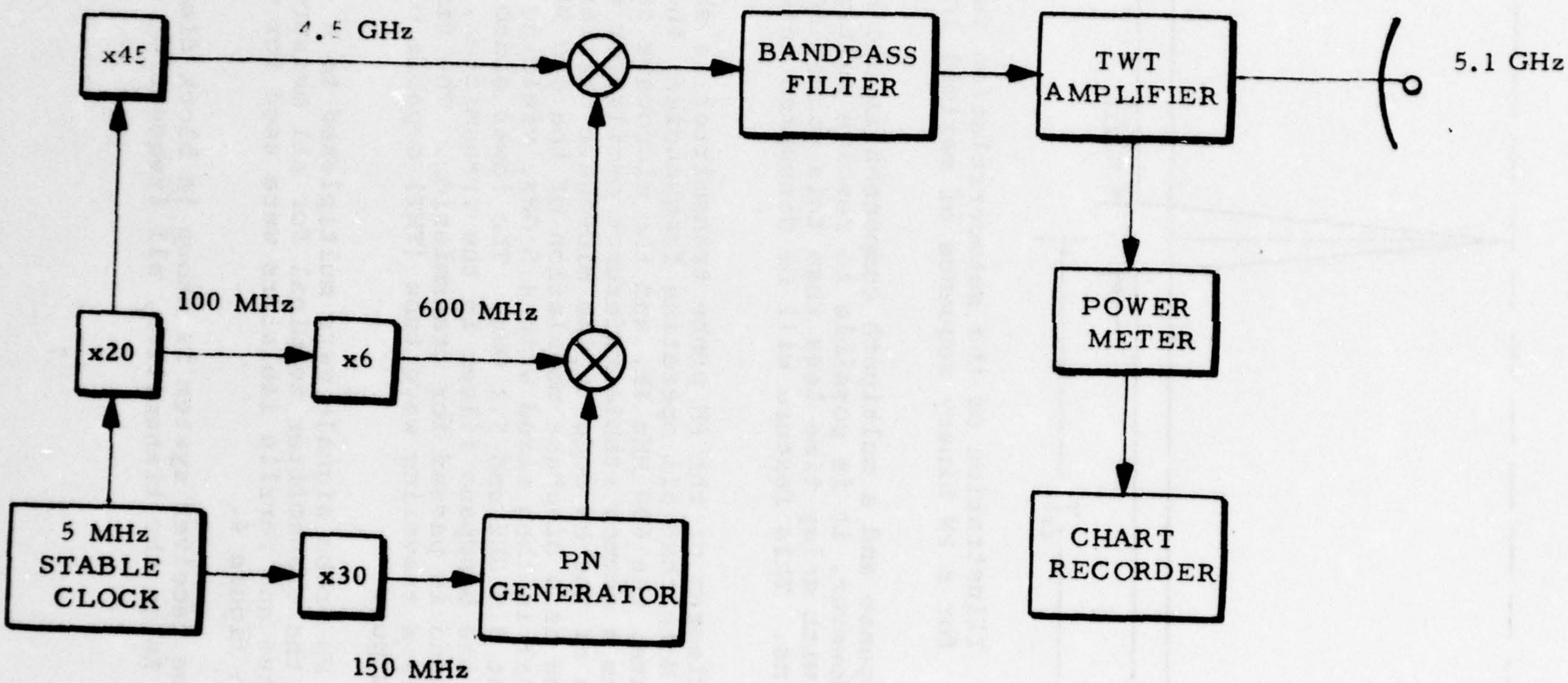

Figure 3. Block diagram of the PN probe transmitter.

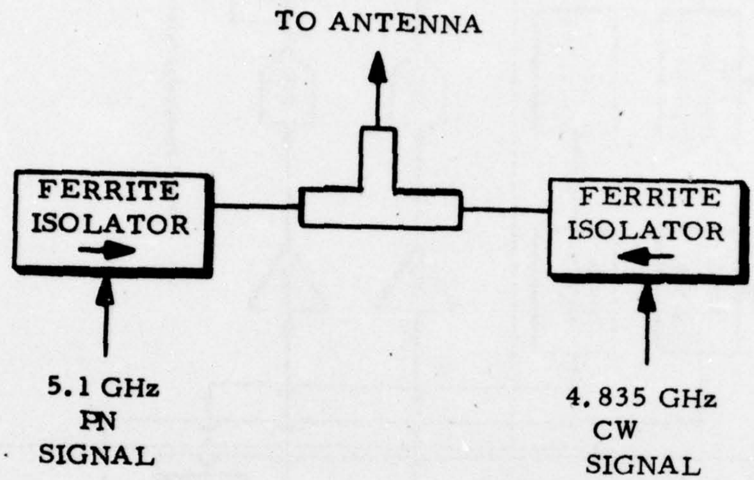

Figure 4. Coupling arrangement for the two test signals into common transmitter antenna.

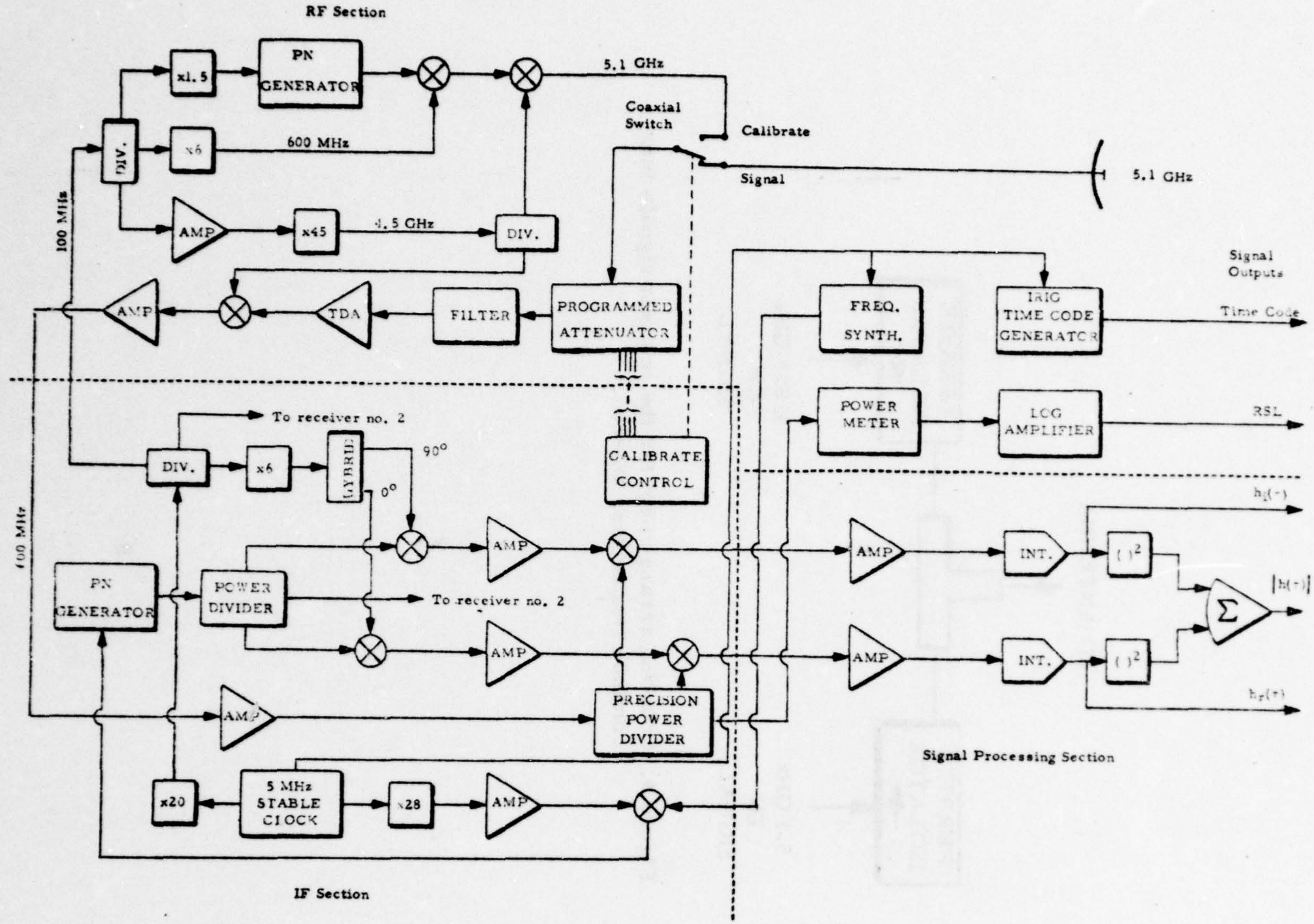

Figure 5. Block diagram of PN channel probe receiver.

are generated from the stable 5 MHz (reference) clock in the receiver. A locally generated PN code is used to modulate the 600 MHz IF in the receiver in the same manner as the transmitter modulation is accomplished. Two IF signals are developed in a quadrature-phase relationship in the receiver to provide a relative phase reference for the received signal. The two modulated IF reference signals are correlated with the received IF signal in identical mixer, amplifier, and integrator chains as indicated in figure 5. The two output signals represent the co- and quadrature-phase (or real and imaginary) components of the channel impulse response. These signals are designated $h_r(\tau)$ and $h_i(\tau)$ respectively. Each of these functions is squared and summed in the receiver to yield the magnitude-squared function, or the power envelope of the impulse response $|h(\tau)|^2$. All of these signals were recorded on magnetic tape during measurement runs, and the power envelope function was continuously monitored on an oscilloscope.

The power envelope function was the primary data signal in the multipath measurements. As noted previously, delayed components can be distinguished down to a delay on the order of 1 ns. The typical response where a multipath component is delayed less than one bit time of the PN code (6.67 ns) is illustrated in figure 6. The theoretical response for both the direct and the multipath components has been drawn on this figure. Note that the delay time can be measured as the separation of the two peak responses, or as a measure of the increased pulse width at the base. Components delayed by more than one bit time will register in the function as a distinct pulse at the appropriate delay along the abscissa.

A complete calibration system is contained within the RF section of the receiver as seen in figure 5. A replica of the transmitter signal is generated, and can be selected by coaxial relay as an input signal to the receiver. A programmed attenuator is also used to provide a range of calibrated levels, or to attenuate a received signal to any desired level. The receiver is designed as a dual unit so that the rf, IF, and signal processing sections are duplicated. The calibration and reference frequency chains are common to both receivers, as is the PN generator used as the local correlation reference.

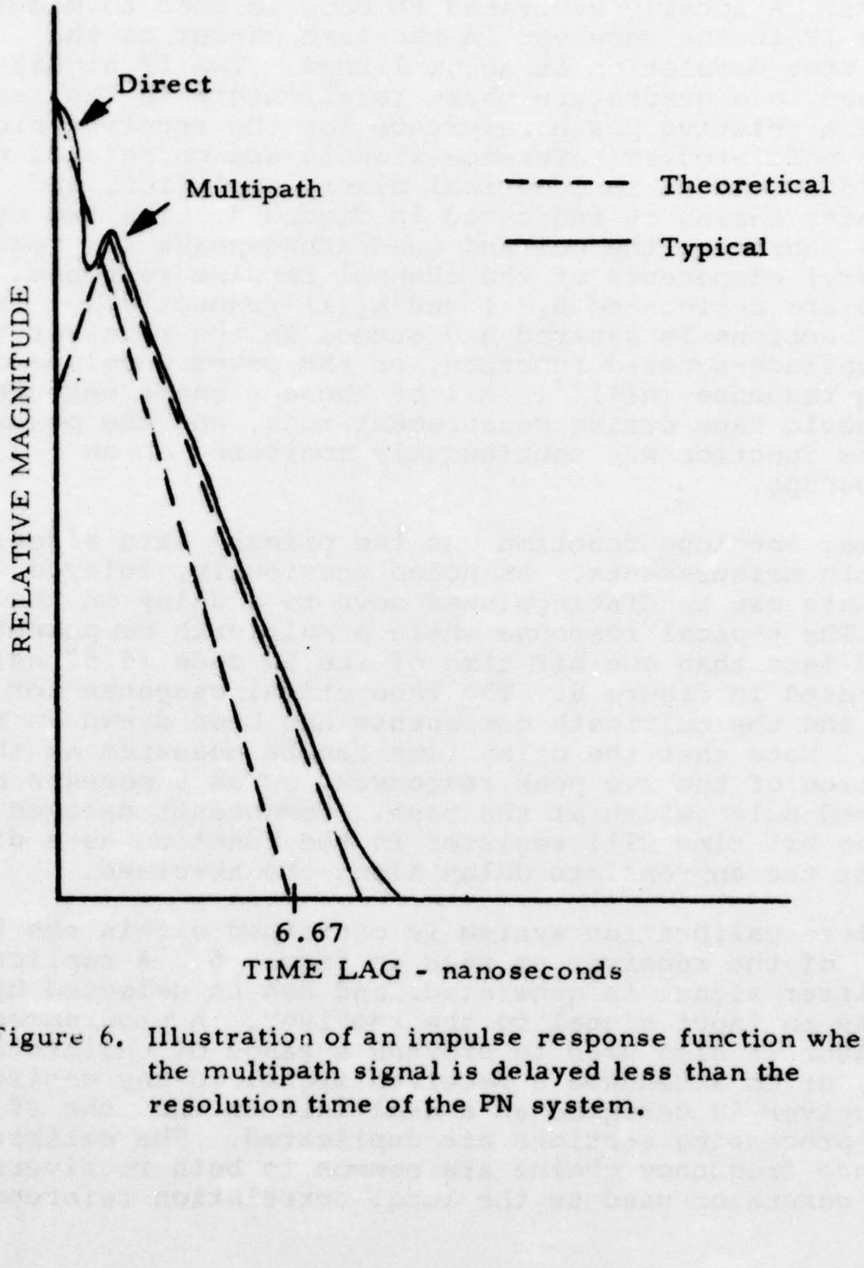

Figure 6. Illustration of an impulse response function where the multipath signal is delayed less than the resolution time of the PN system.

The correlation process is accomplished in the receiver in a dynamic mode, by clocking the local PN generator at a slightly slower rate than the corresponding generator in the transmitter. This has the effect of allowing the local PN signal to slowly "drift by" the received signal, thus producing a dynamic time lag between the two signals. For example, a normal setting for the MLS multipath measurements was a receiver clock rate slowed by approximately 1 kHz. This results in a shift of about 0.023 ns per sequence in the correlators, for a code of length L=511 bits. At this rate, approximately 150,000 sequences (or code words) are multiplied and averaged in the correlators for a complete correlation "window" (approximately 3.4 ns). Thus the total process time required to produce a correlation function at the output is 0.5 s in real time, but is equivalent to a window of 3.4 μs. This is an example of the time/bandwidth trade-off made in the correlation model. The slow PN clock rate for the receiver is variable, and is controlled by the frequency selected in the synthesizer shown in figure 5. The window length can also be changed in the system by selecting different sequence lengths L. More details of this process may be found in Linfield, et al., (1976). This example defines the parameters selected for the MLS experiments, and shows how the measured impulse functions were updated every 0.5 s.

In addition to the three impulse functions already mentioned, a power level measurement was made on the IF signal and recorded through a logarithmic amplifier for the received signal level (RSL) in the PN probe. A standard IRIG "E" time code signal was also generated and recorded for use in data processing and analysis. All of the data signals and the time-code were recorded on a 1/2" magnetic tape recorder, and the RSL data were continuously monitored for both the cw and PN receivers on a paper strip chart recorder. One minute timing marks developed from the time-code generator were also recorded on the strip chart record.

2.2 General Facilities

2.2.1 Transmitters

The microwave test equipment described in section 2.1 was housed in mobile units for the multipath measurements. The

transmitters were mounted in a small trailer equipped with workbench and equipment racks. The trailer was pulled by a pick-up. This transmitter trailer is shown in figure 7. Two transmitter antennas were used alternately in the experiments. The first was a standard gain (10 dB) microwave horn, which was mounted on a mast affixed to the rear of the transmitter trailer. The second antenna was a 6 ft* parabolic reflector with a center feed horn tuned for 5.1 GHz. This antenna was mounted on the rear of a semi-trailer tractor vehicle. The parabolic antenna is shown, being assembled, in the photograph of figure 8, which also illustrates the mounting arrangement. The "fifth wheel" of the tractor was removed, and replaced with a two-plane gimbal-type mounting surface for the antenna mast. The gimbal mounting permitted an accurate and speedy method to plumb the antenna mast vertically for any parked position of the tractor. A precision, hand-cranked azimuth control unit was mounted on the top gimbal plate. This unit formed the base for the mounting mast (5" steel pipe)*, and provided precision control and measurement of the azimuth angle of the parabolic antenna. The elevation control for the antenna consisted of a lag-screw adjustment in the mounting bracket. In addition to this, a telescopic sight was mounted to the dish and aligned to point at the center of the pattern at a distance of 200 ft.

Primary power for the transmitter equipment was furnished from a diesel powered generator that was an integral part of the semi-tractor. This unit can be seen directly behind the cab in the photograph of figure 8. It was capable of several hours of continuous operation before refuelling was necessary. A line-voltage regulator was used to stabilize the power for all operating equipment.

A typical configuration for the transmitter terminal is shown in the photograph of figure 9. Here both transmitting antennas can be seen, and the low-loss foam flex cable used to couple the signals to either antenna is shown extending through a port in the side of the trailer to the standard gain horn. Both antennas were mounted so as to maintain the feed horn of the dish and center of the horn at approximately 10 ft above the surface. The azimuth for the horn antenna was changed by rotating the aluminum mast as required.

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*1 ft = .3048 m

*1 in = 2.54 cm

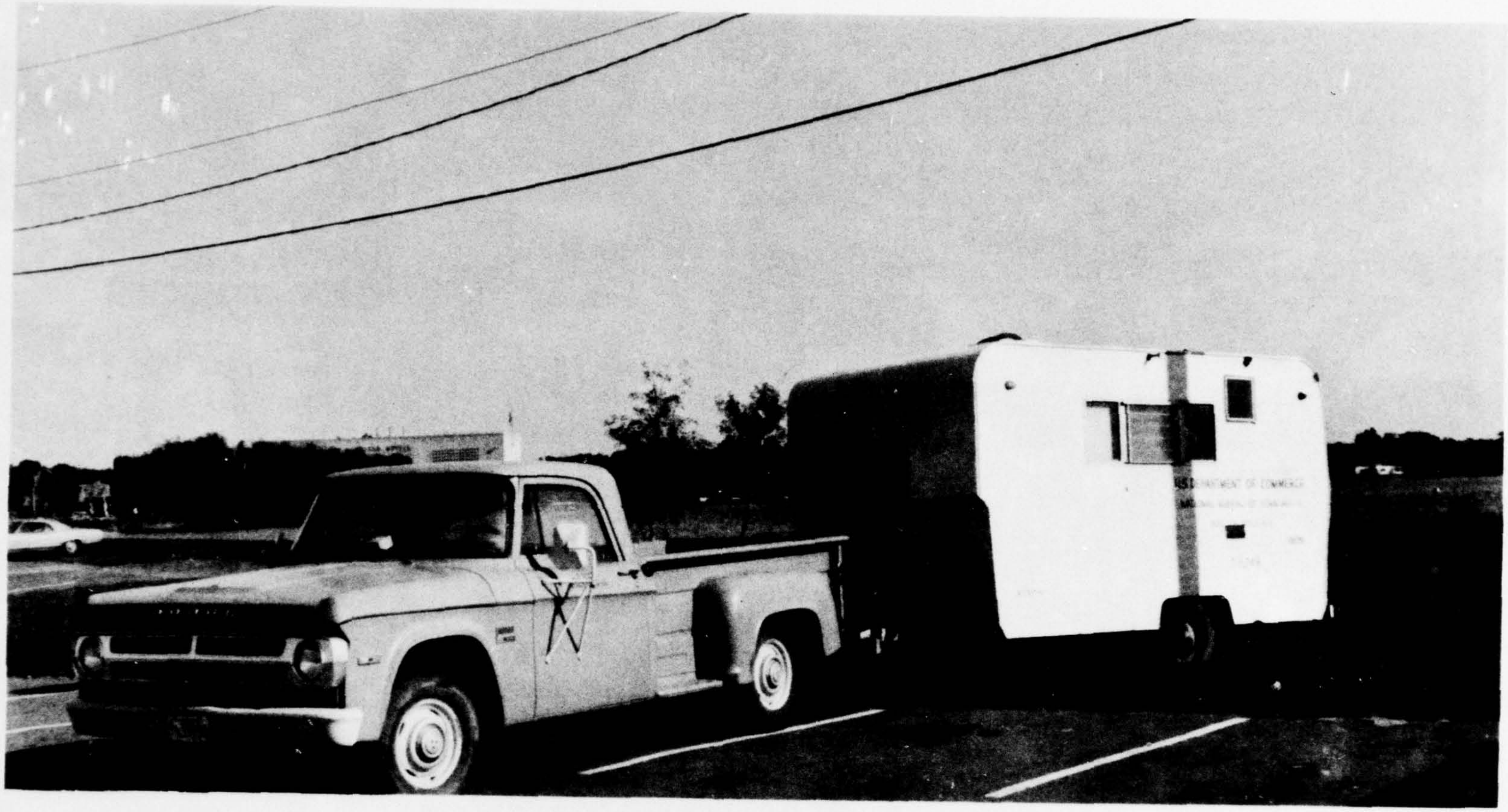


Figure 7. Photograph of the transmitter trailer and pick-up vehicle.

Figure 8. Photograph of the tractor-mounted parabolic antenna being assembled at Logan Airport.

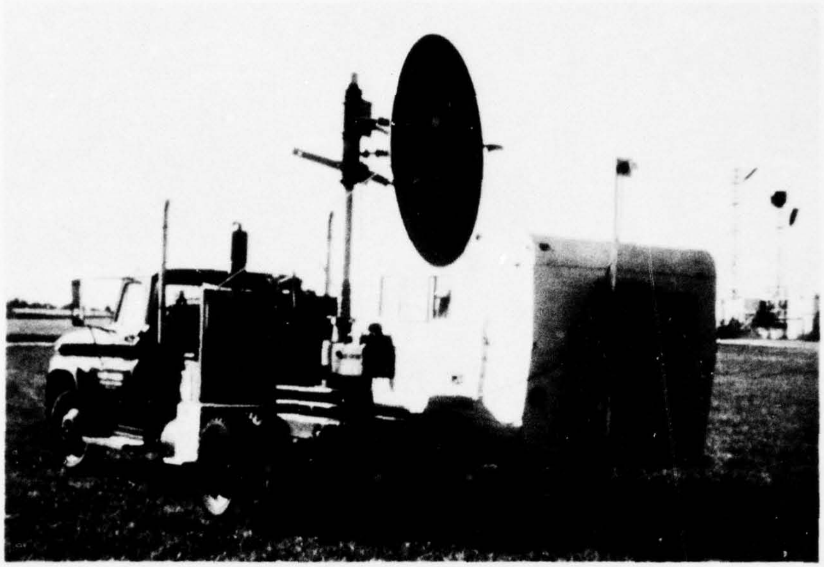


Figure 9. Photograph of typical transmitter cofiguration.

Figure 10. Photograph of FAA MLS mobile van used for receiver terminal.

2.2.2 Receivers

The mobile van shown in the photograph of figure 10 was furnished by the FAA to house all of the receiving test equipment. The van was designed specifically for use in the MLS Phase II test program, and was made available for use in the multipath experiments. The interior was well-equipped with rack space for mounting of equipment, workbench and desk space, and all necessary communication equipment so that the driver was in constant contact with the FAA ground controller at the airport. The vehicle was equipped with an integral power generator and regulator system capable of handling the requirements for all test equipment. A telescoping mast seen in figure 10 was used to mount all antennas for the receivers. This mast had a fixed height section 25 ft firmly attached to the vehicle and a movable section that could be raised and lowered with a motor driven control unit. The total height of the extended mast was approximately 50 ft. A four digit counter calibrated in feet was part of the control mechanism, and gave a visual read-out of the mast height to the nearest hundreth of a foot. In addition to the telescoping mast, a 25 ft fiberglass extension mast in length was used for many of the measurements. The extension permitted a total height for a receiving antenna of 75 ft above the ground. Whenever the extension was used, three light tether lines, attached to the top and a supporting star guide near the center, were used to minimize any sway or twist in the mast. The tether lines were either held by hand, or anchored to concrete blocks when the van was parked in the desired locations. The extension mast and the tether arrangement can be seen in both figures 10 and 11; figure 11 shows the van in an operational position on a runway.

Signal lines to all antennas on the mast of the van were type RG-2/4/U coaxial cable. A total of three cables were used, each about 50 ft in length. The cables were bundled together, and laced with a nylon line which supported the free-hanging weight of the cables in order to relieve any strain on connectors. The cable assembly can be seen in figure 10, looped along the raised mast. The extension mast was constructed with a coaxial cable permanently embedded through the center of the tubing. Connections were made at the base of the extension mast to this cable for the top-most antenna.

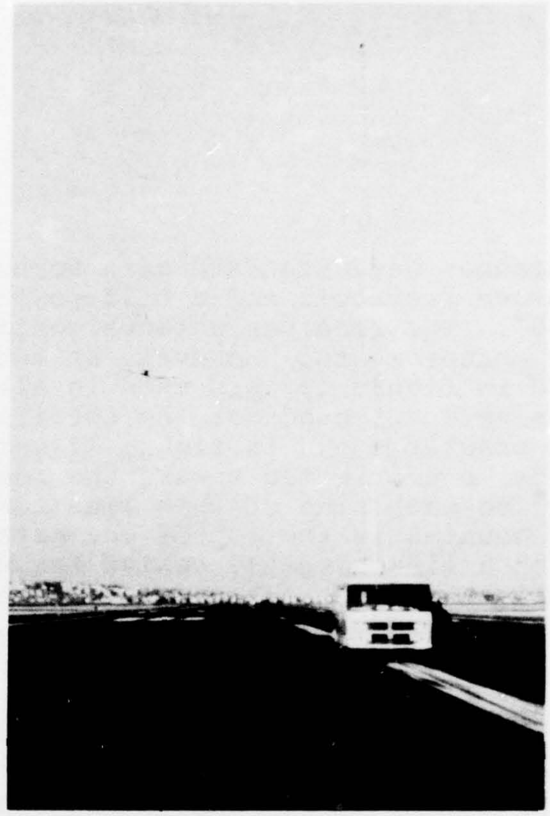


Figure 11. Photograph of the mobile receiver van in an operating position on a runway at Logan Airport.

All receiver antennas were standard gain horns with a nominal gain of 10 dB above isotropic and a half-power beamwidth of approximately 45°. The receiver antenna configurations varied during specific measurements. However, an antenna mounting system, outlined in figure 12, was used in all instances. The individual horns were selected for the specific geometry of each test. The bracket shown in figure 12 was designed to mount three horns, one oriented toward the rear of the van and one oriented 30° to each side of this line toward the rear. A single horn was mounted at the top of the extension mast (when used) oriented on a line directly behind the van. Actual positions and heights of the antennas are noted in the following sections on measurement.

2.3 Antenna Patterns

The antennas used in the experiment were measured for their radiation gain patterns. These data were later used in evaluating the experimental results. The parabolic antenna was elevated 1.6° above the horizontal in order to minimize ground reflections from the main lobe. The pattern measurements were made at selected locations on the perimeter of the airport that provided as level a location as possible, and free of adjacent buildings or other objects that could affect the results. The receiver van was located 200 ft from the parabolic antenna, and a receiver horn was raised in height on the van mast to maximize the received signal. The horizontal pattern was then measured by rotating the dish in known increments of azimuth angle. The 4.835 GHz cw system was used for these tests, and the receiver was calibrated with use of a precision attenuator to establish relative signal levels. The vertical pattern for the dish was measured using two configureation. For elevations above the main lobe, the dish was oriented as above and the receiver horn antenna was lowered from a height of 50 ft down to 5 ft above the surface. Signal level recordings were made every 5 ft over this span, and the data provided a measure to an angle of approximately 1.6° below the main lobe center. The lower half of the vertical pattern was measured by positioning the receiver horn at 45 ft above the surface, using optics to orient the dish elevation angle (approximately 9.93°) toward the receiver horn, and again lowering the receiver mast in 5 ft increments. The two halves of the measured pattern were then

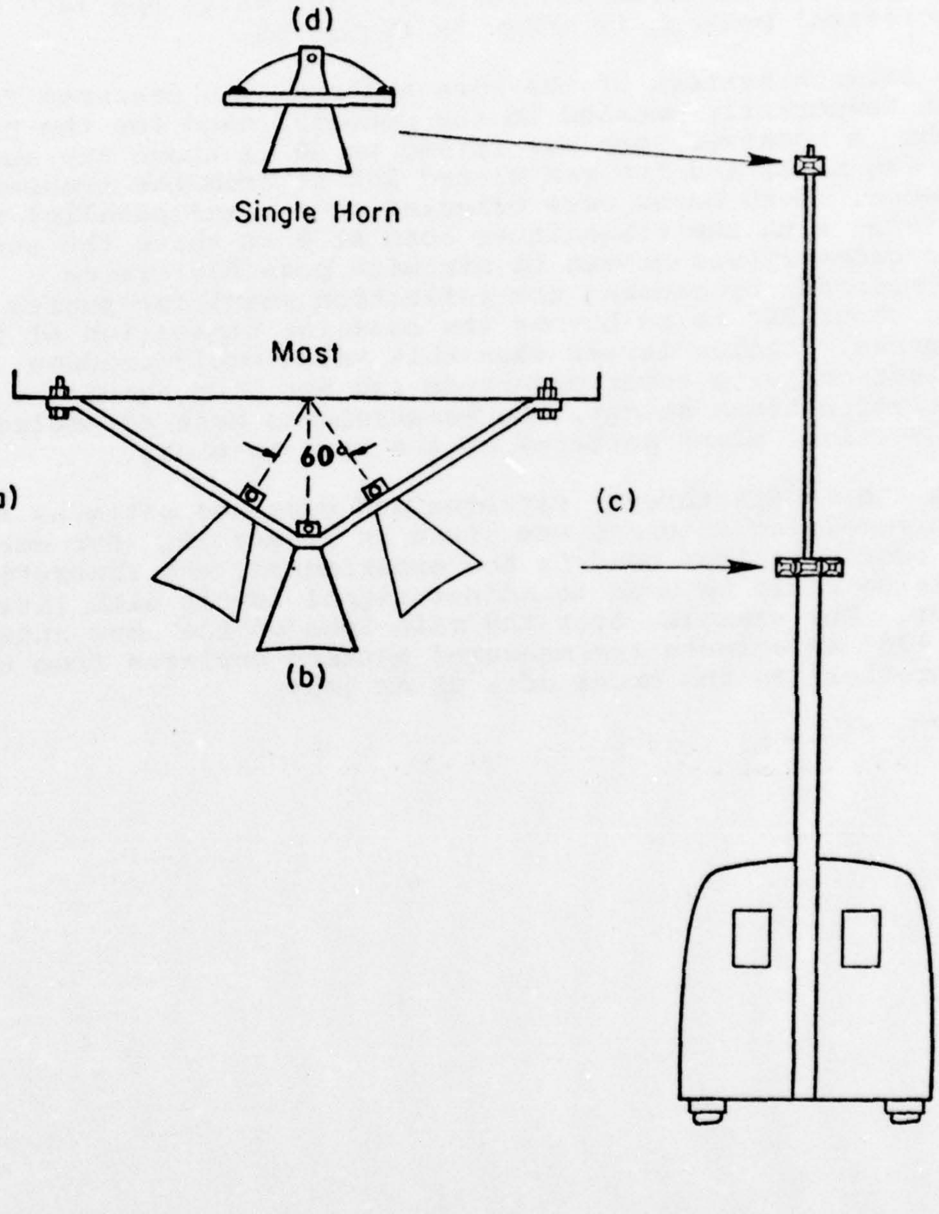


Figure 12. Antenna mounting arrangement on the receiver van.

combined (equalized in level) at the center of the main lobe. The measured patterns are shown in figures 13 and 14. The theoretical pattern is shown in figure 15.

The azimuth pattern of the horn antennas was measured for one unit temporarily mounted to the pedestal used for the parabolic dish. A receiver horn was raised to 50 ft above the surface on the van mast, and the van placed 102 ft from the transmitter antenna. Both horns were oriented on a plane parallel to the surface, with the transmitter horn at 9 ft above the surface. This geometry was chosen to minimize possible ground reflections, by causing the reflection point for angles less than about 26° to be beyond the baseline separation of the antennas. Angles larger than this value would produce reflections with lower magnitude and arriving above the receiver antenna height. No measurements were attempted for the vertical plane patterns of the horn antennas.

Both the manufacturers' patterns and measured patterns for the horn receiving antennas are given in figure 16. For most of the configurations used in the experiments, the theoretical patterns could be used to adjust signal levels with little error. For example, over the main lobe of the horn antennas for $\pm 30°$ in azimuth the measured pattern deviates from the theoretical on the order of 2 dB or less.

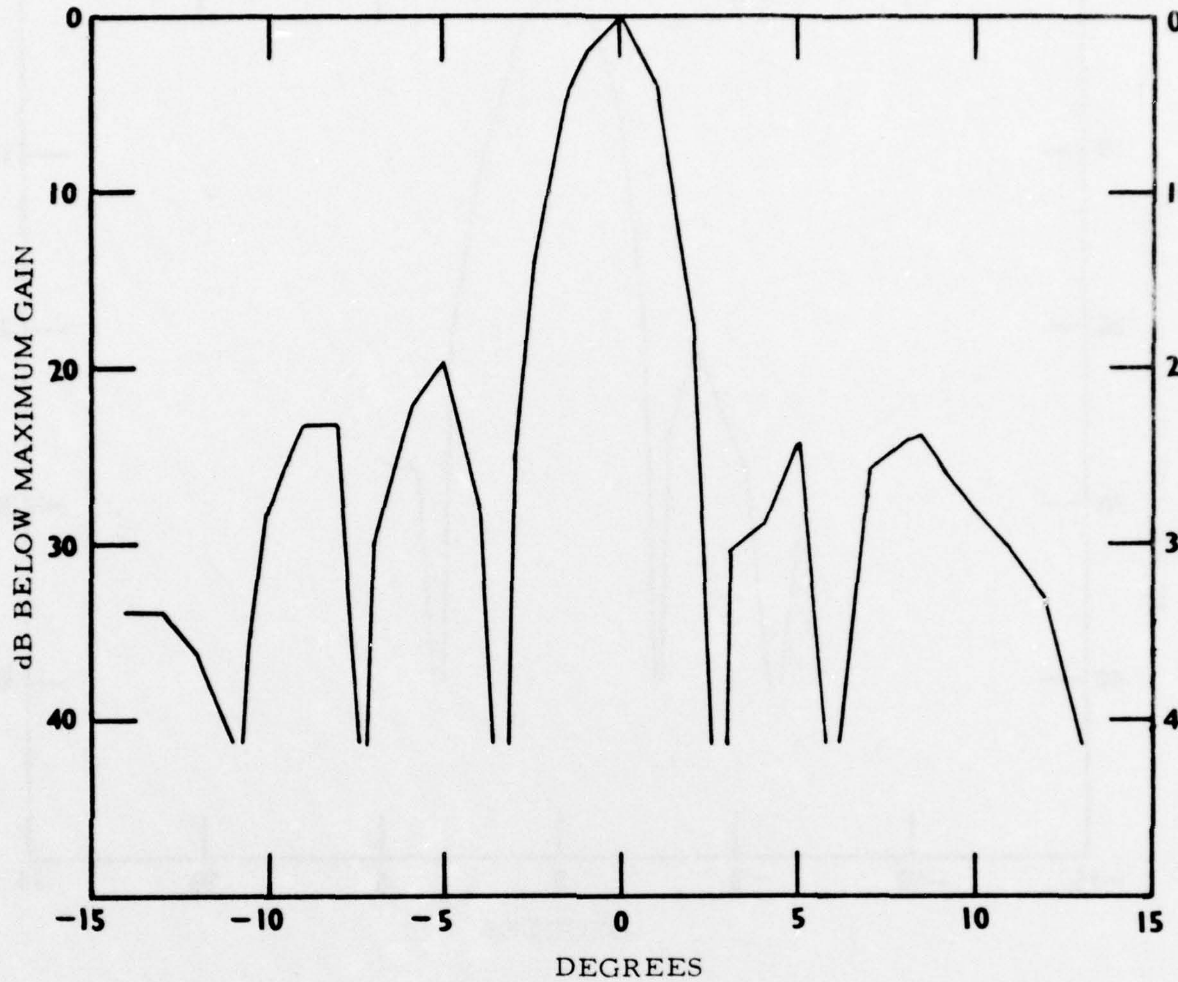


Figure 13. Measured azimuth pattern of the 6 ft parabolic transmitting antenna.

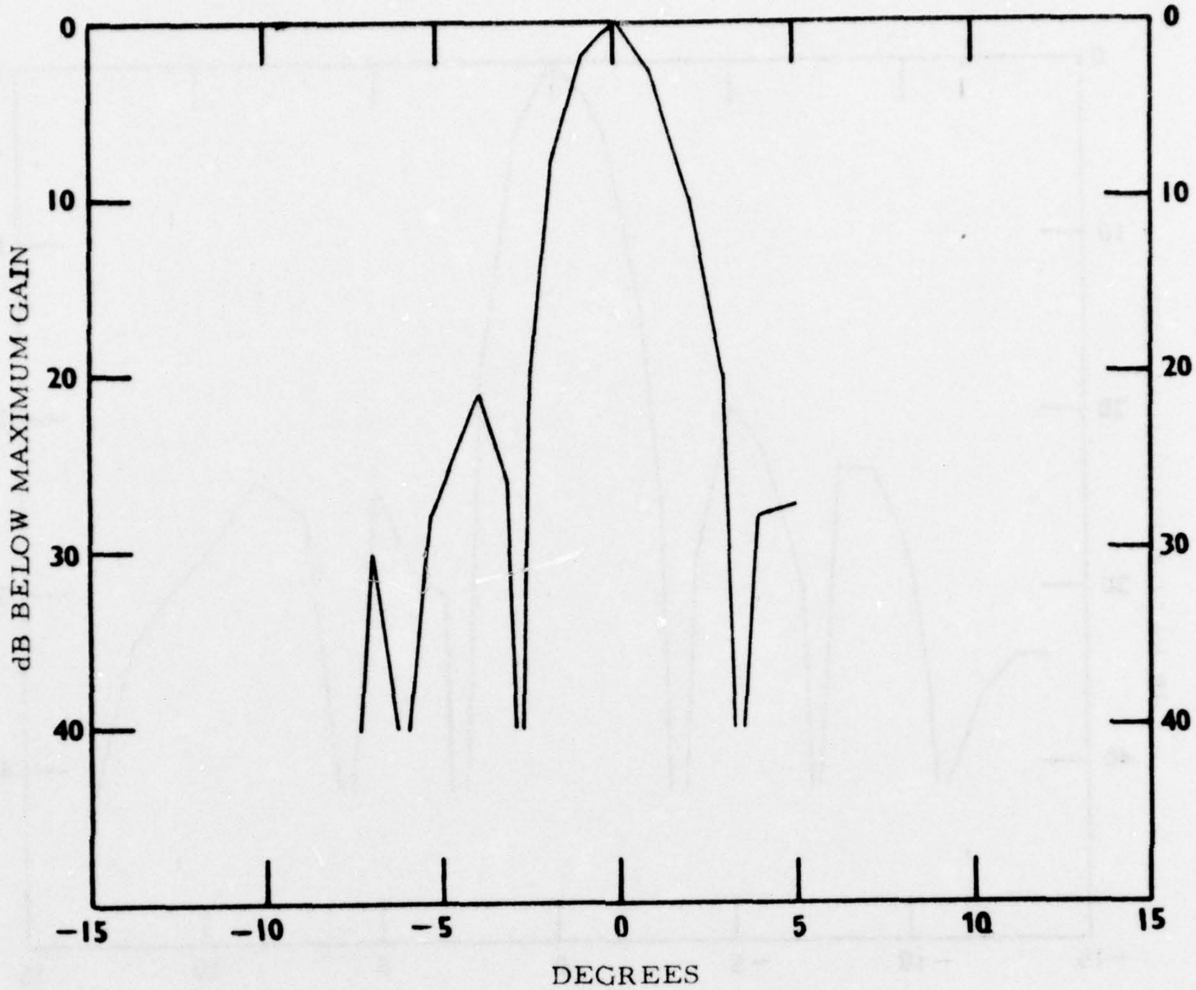


Figure 14. Measured elevation pattern of the 6 ft parabolic transmitting antenna.

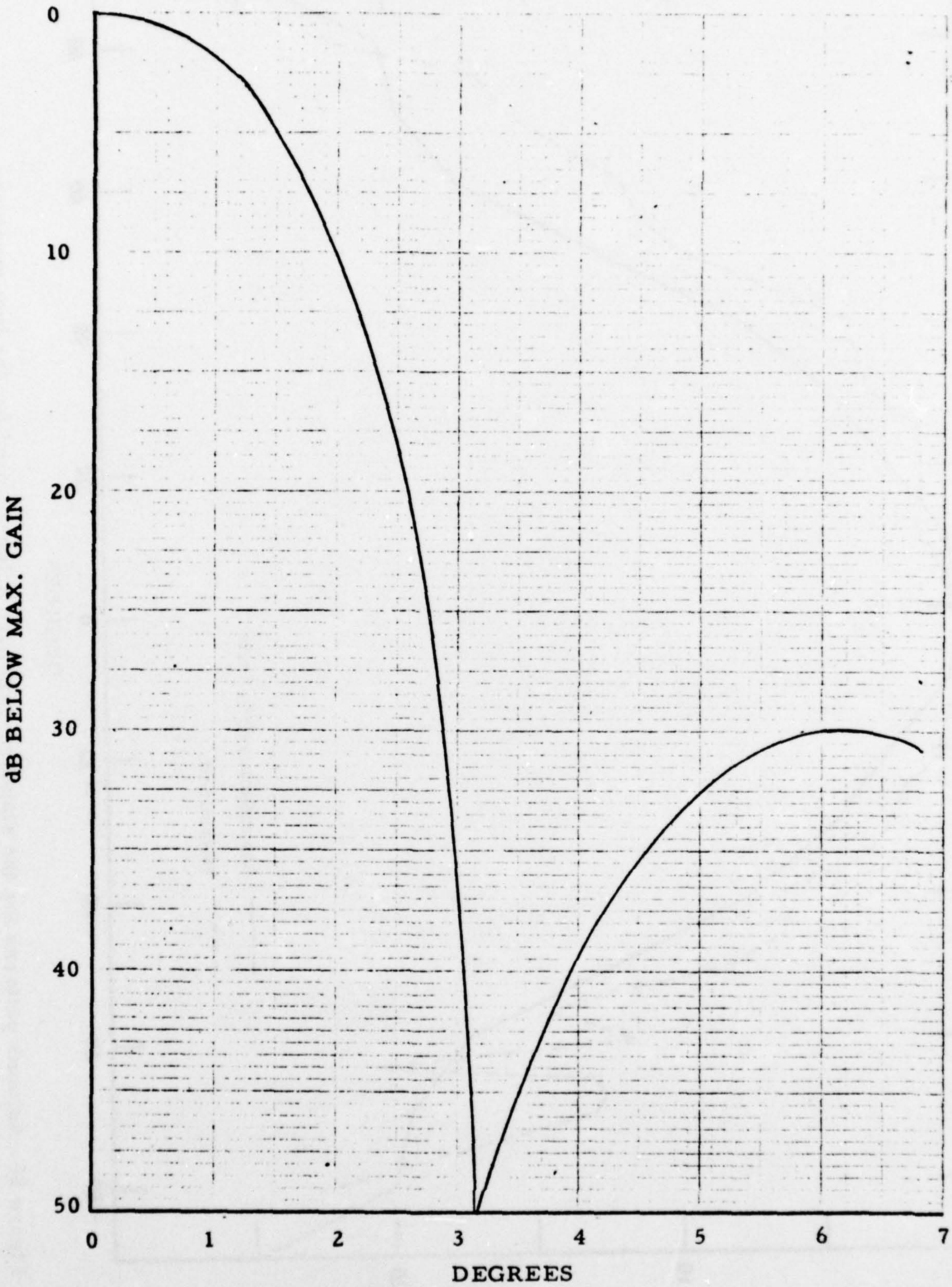


Figure 15. Calculated azimuth pattern of the 6 ft parabolic antenna at 5.1 GHz.

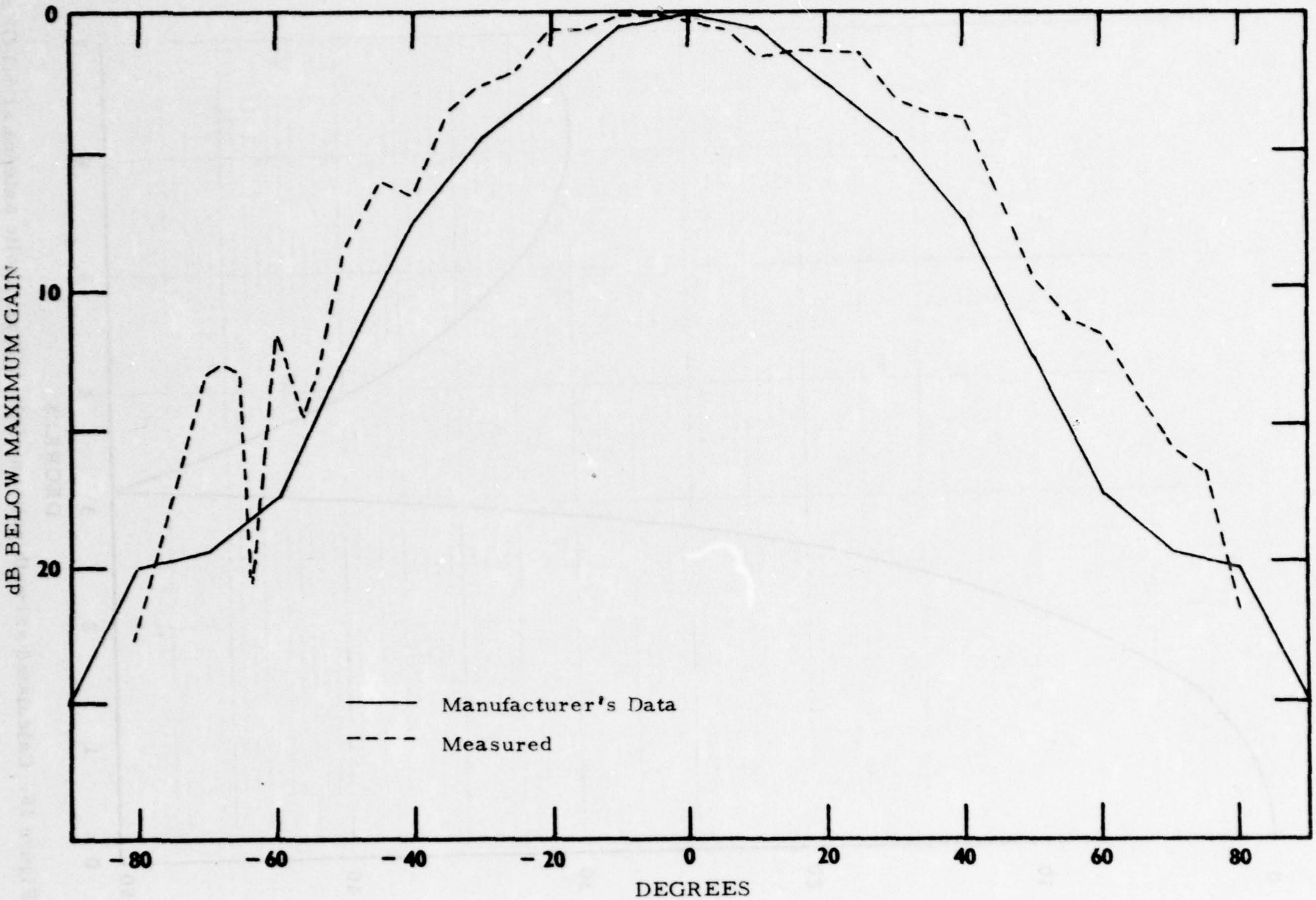


Figure 16. Azimuth patterns for the standard-gain horn antennas used for the test receivers.

3. PRELIMINARY MEASUREMENTS

ITS representatives of the FAA/MLS program assisted the team in preparing the receiver van for operation, and briefing the team in its operation. An experienced driver was assigned to the van by the FAA; one who was completely familiar with ground control requirements and procedures at the NAFEC airport. The driver had the responsibility of maintaining radio contact with the ground controller in the operations tower. Vehicle and personnel passes were issued by the FAA.

The receiving equipment and all data recording facilities were mounted and secured in the van. The transmitters were assembled in the ITS trailer and tested for proper operation. The ITS furnished a licensed set of communication transceivers, which were used for communication between test team members at the transmitter and those at the receiver. Preliminary tests and calibrations were performed prior to the site measurements. One preliminary test consisted of placing the transmitters at one end of an inactive runway, STOL 17/35, with signals radiated from the wide-angle horn antenna. The receiver van was driven slowly down the center of the runway. Both test signals were monitored and recorded during the run to observe any multipath signals that might reflect off buildings or other structures on the edge of the runway. For this run, the cw receiver was connected to the center horn (b) of figure 12. The two channels of the PN receiver were connected to the two side-looking horns (a) and (c) of this figure. The mast was raised to 50 ft and held at that height. The cw signal indicated the normal loss versus distance, and no significant off-path reflections were observed on either of the PN channels. However, ground reflections could not be avoided in the configurations, so the cw signal displayed a scalloped pattern as a result of ground reflection interference. The buildings consisted mainly of low (one story) structures used by the Air Defense Command on the west side of the runway, and the former terminal building for the Atlantic City municipal airport on the opposite side nearest the transmitter location. The receiver van was then positioned along the runway at several points to observe possible reflections from the Air Defense Command buildings. The transmitters were switched to the parabolic dish, and this antenna was slowly changed in azimuth to illuminate the buildings. Several fixed receiver locations were chosen, but no significant reflections were observed for

any position. Thus, we concluded that this particular cluster of structures presented no serious multipath problem. A diagram of the NAFEC/Atlantic City airport is shown in figure 17. The path of the receiver van for these tests began on the end of the runway near taxiway H and continued to the north near taxiway C. Van positions were logged relative to particular runway and taxiway center lines, established test points for MLS, and other fixed landmarks.

The second measurements performed at NAFEC made use of the reflecting screen that had been used in the MLS Phase II test program. The screen was positioned off the runway in a grassy area near the STOL 17/35 runway. The transmitter was located on a roadway that was on an extension of the runway center line to the south. These positions are sketched in figure 17. The reflecting screen was mounted on the side of a semi-trailer, and had the approximate dimensions of 45 ft long by 25 ft high. The screen was positioned 250 ft west of the runway center line, and angled with respect to this line by approximately 15°. The north end of the screen was further toward the west. The distance from the transmitter to the center of the screen measured 500 ft at a 30° angle from the center line; thus placing the center line of the screen perpendicular to the runway, approximately 433 ft from the transmitter. This configuration was used to simulate the azimuth multipath tests performed in the MLS Phase II program with the transmitter positioned directly on the center line of the runway. In order to simulate the elevation test geometry, the screen was left in its original position and the transmitter was moved to a point 200 ft to the west of the runway center line, and 200 ft from the center of the screen on a line parallel to the runway. Both of these configurations are sketched in figure 18.

For both tests, the receiver van was driven down the STOL 17/35 runway to the intersection of runway 4/22, starting from a point near the intersection with runway 8/26. In each case, the cw receiver used the rear-looking horn (b) in figure 12 and the PN receivers were connected to the side-looking horns (a) and (c). The mast was maintained at a height of 50 ft. For the azimuth configuration, the van was driven along the center line of the runway. For the elevation configuration, the van was driven along the east edge of the runway to simulate the offset location of that portion of the MLS. The results of

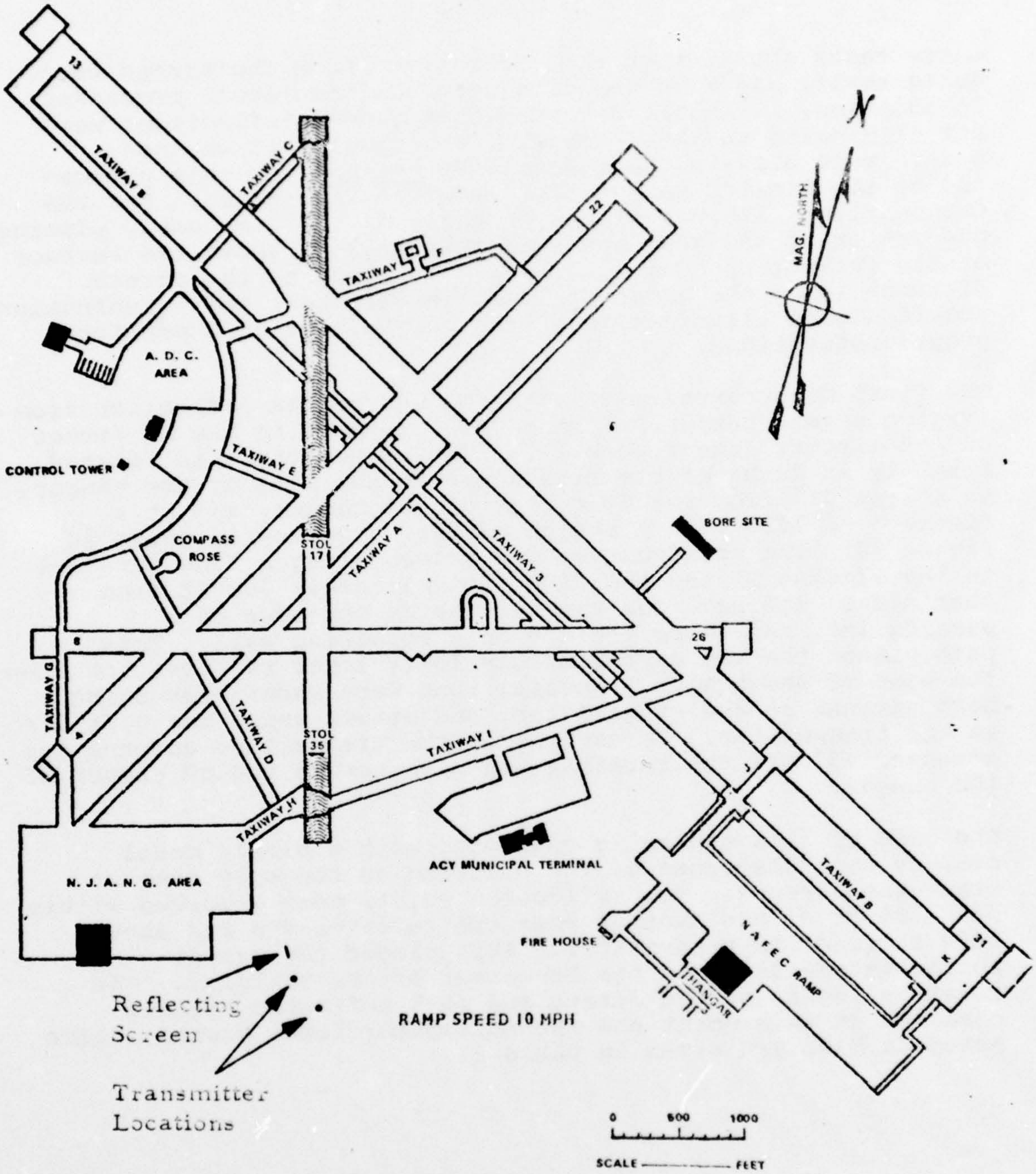


Figure 17. Diagram of the NAFEC/Atlantic City Airport, Atlantic City, New Jersey.

these tests showed that the reflections from the screen were quite small, and thus the data were not completely processed. In addition, it should be noted that ground reflections were not eliminated in these tests. For example, it was not possible to elevate the transmitter antenna for this purpose due to the limited height of the reflecting screen. For the transmitting dish, an elevation angle of 0.6° was used, placing the center of the beam approximately 15.2 ft above the surface at the reflecting screen. The 2° beamwidth at the screen distance is on the order of 17 ft in diameter; this combination provided good illumination of the screen, but also permitted ground reflections.

The final measurement made at NAFEC was of the reflection from a large concrete hangar building (301) located in the SE corner of the airport (see figure 17). The transmitter was located directly in front of the fire house to the west of the hangar, on a line 45° from the SW corner of the hangar, and at a distance of 1000 ft. A sketch of this geometry is shown in figure 18. The receiver van was driven along a line parallel to the SW side of the building, approximately 700 ft from that side. The path for the van was at the edge of a parking lot, and along the top of a retaining wall. This path placed the van approximately 10 ft lower in elevation than the base of the hangar. Several runs were made; some using a horn antenna at the transmitter, and others using the 6 ft dish at the transmitter. In each case, the transmitter antenna was oriented 45° off the receiver van path toward the SW corner of the hangar.

The side of this hangar is concrete, with a single metal doorway near the front of the building as the only item to break the surface. Two reflection points were observed within 50 to 60 ft of one another when the receiver van was about 1420 ft from the transmitter. This placed the van at approximately 35° from the SE corner of the building. The relative levels of the direct and peak reflected signals observed at this point and the multipath/direct signal ratios noted as M/D, are given in table 1.

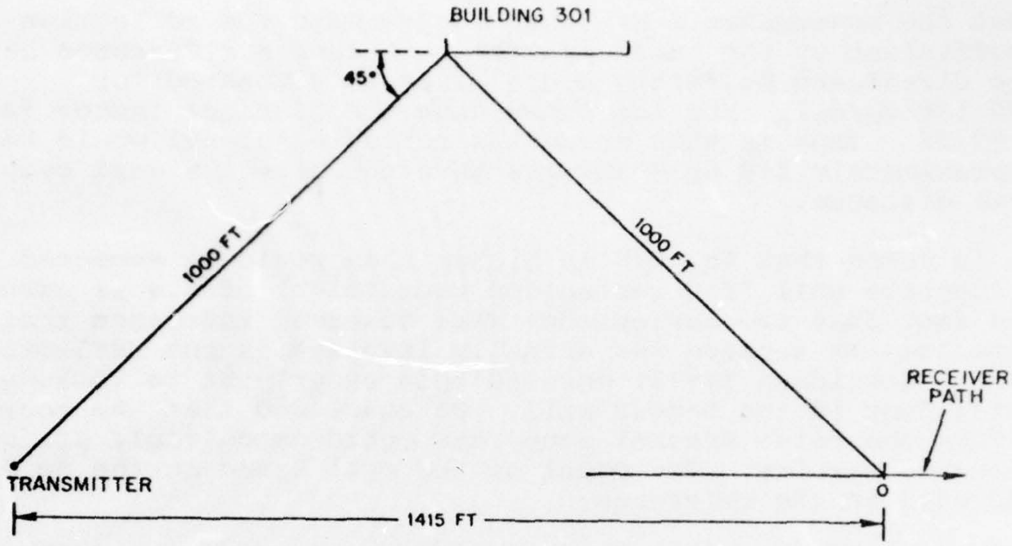


Figure 18. Geometry for the measurements on the NAFEC hangar (building 301).

Table 1

Reflection data from NAFEC hangar (building 301).

Run No.	Tx Antenna	Direct** Signal (dB)	Reflection** Signal (dB)	M/D (dB)
* 1	6' dish	+13.5	+7.6	-5.9
1	6' dish	+13.5	+8.6	-4.9
* 2	Horn	-4.0	-8.0	-4.0
2	Horn	+1.5	-3.2	-4.7

* Denotes a time-average response.
** Values relative to calibration levels only.

When the measurements are used to estimate the reflection coefficient of the building, the path length difference between the direct and multipath signal must be accounted for ($20 \log d_m/d_o$). For the above data the distance factor is 2.97 dB. Thus in this case, the reflected signal would be approximately 1.9 or 2 dB less than the direct signal over the same distance.

It is noted that the M/D is higher than would be expected for a concrete wall if a reflection coefficient of 0.4 is assumed. The fact that two reflections were observed indicates that a more complex surface was actually involved in the reflection data. Schnidman (1975) modeled this experiment to include the metal door in the hangar wall. He concluded that the door was within the first Fresnel zone, and could conceivably produce the measured results. The model of the wall based on the cw data is included in the reference.

Measurements were also performed using the NW face of the hangar building as a reflection surface. This side of the building has several sliding-door sections of steel framework and a corrugated surface. The sections are staggered so that the face presents a rather complicated surface. It was not possible to eliminate ground reflections from the measurements, and during runs the sliding doors were opened at various times. These data were thus not processed sufficiently to characterize the resulting multipath.

4. MEASUREMENTS AT LOGAN INTERNATIONAL AIRPORT

Following the preliminary measurements above, the test team and all equipment were moved to Logan International Airport in Boston, Massachusetts. A general plan of the airport is shown in figure 19.

Arrangements for the experiments were made by MITLL personnel with the Massport Authority as noted previously. The experiments were conducted during one period in October 1974 and a second period in December 1974.

The specific tests performed were selected to satisfy the needs of MITLL, in support of their multipath modeling work. These tests included measurement of multipath data from hangar buildings, terminal buildings, and large jet aircraft. Figure 20 is a sketch of the major runways and building positions at Logan Airport that were significant to the experiments (Shnidman, 1975). Positions of the test transmitters and the receiver van are indicated in this figure for the majority of the tests made. Each position is noted with a subscript (used in later text) so that the general test configurations may be seen at a glance. More detailed geometries for specific tests are indicated in the discusssion of each test presented below. Test results have been grouped according to the reflecting object as noted above.

4.1 Multipath from Delta Airlines Hangar

The maintenance hangar of Delta Airlines (building 21 in figure 20) was selected as a typical structure found at many major airports, and in a location convenient for the measurements. Distances from the structure were limited by other buildings, etc., in the area, but were considered adequate. The hangar is constructed in two sections as seen in figure 21. The smaller section is a metal-clad structure with glass windows, and the larger section is of cinder-block with fiberglass material in the large hangar doors. For these tests, the transmitter was located near the Pan American Airfreight Building, and is designated T_6 in all figures. The receiver was fixed in three positions noted as R_6, R_6', and R_6'' in figures 20 and 21.

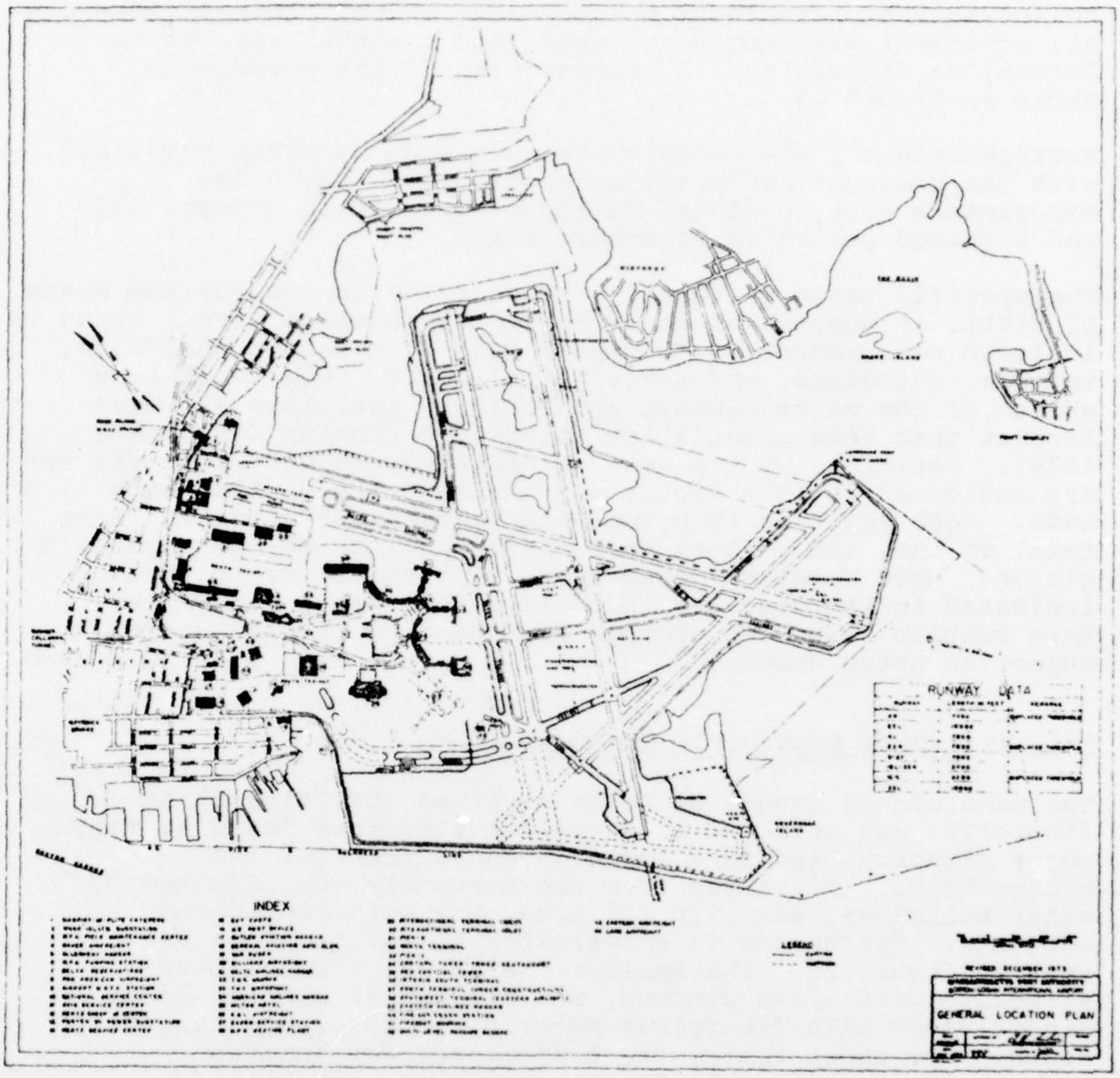


Figure 19. General location plan of Logan International Airport, Boston, MA.

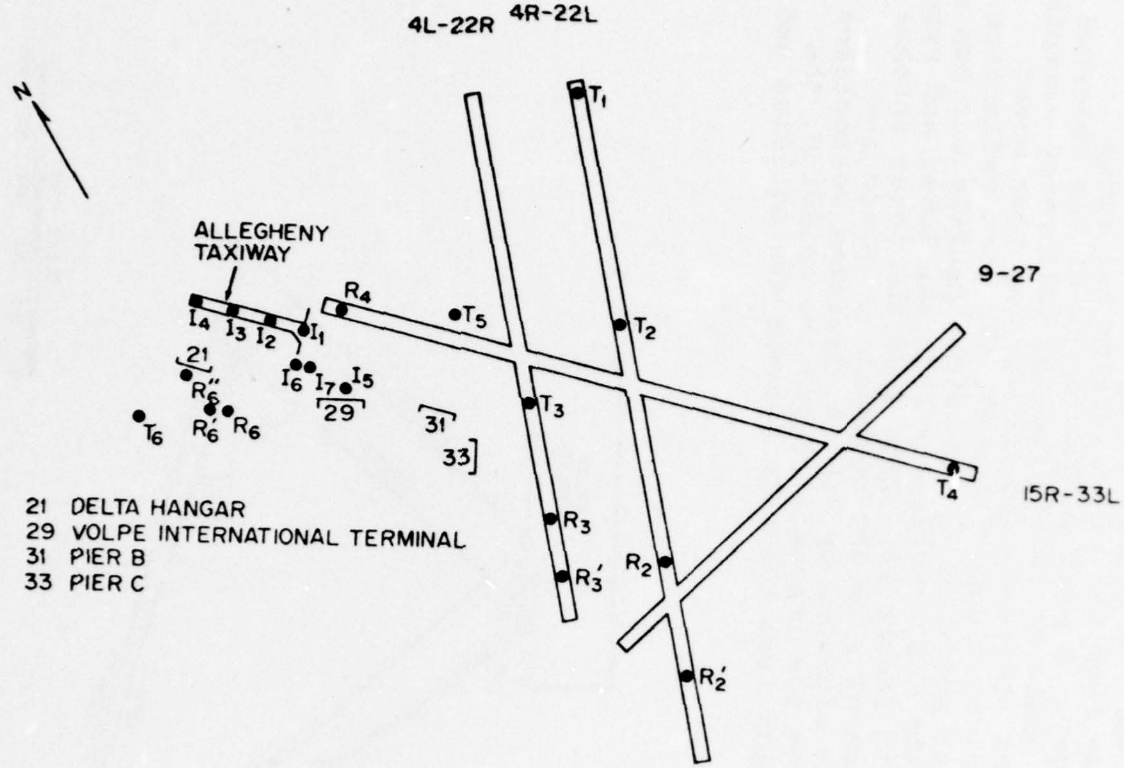


Figure 20. Sketch of the major runways and buildings at Logan International Airport. Positions of the transmitters and the receiver van are indicated for most of the measurement configurations.

Figure 21 shows the geometry for each receiver position. The first receiver position R_6' was used for calibration of the receivers, with the transmitter dish oriented directly toward the van. The transmitter dish was then swung in azimuth away from the van directing the radio beam toward the hangar. A peak reflection level was observed with the dish at an angle of 37.5° from the calibrated azimuth. A reference level was recorded, and the van was then moved backward (dashed line in figure 21) until the peak reflection level was observed at position R_6'. A height profile was run at this position, and the M/D results for both the lower and upper antennas are shown in figure 22. Data from the lower antenna indicate the presence of a ground reflection. Since the transmit antenna was elevated by 1.6° to minimize reflections from the path between the transmitter and the building, the reflection is probably from the path between the building and the receiver van.

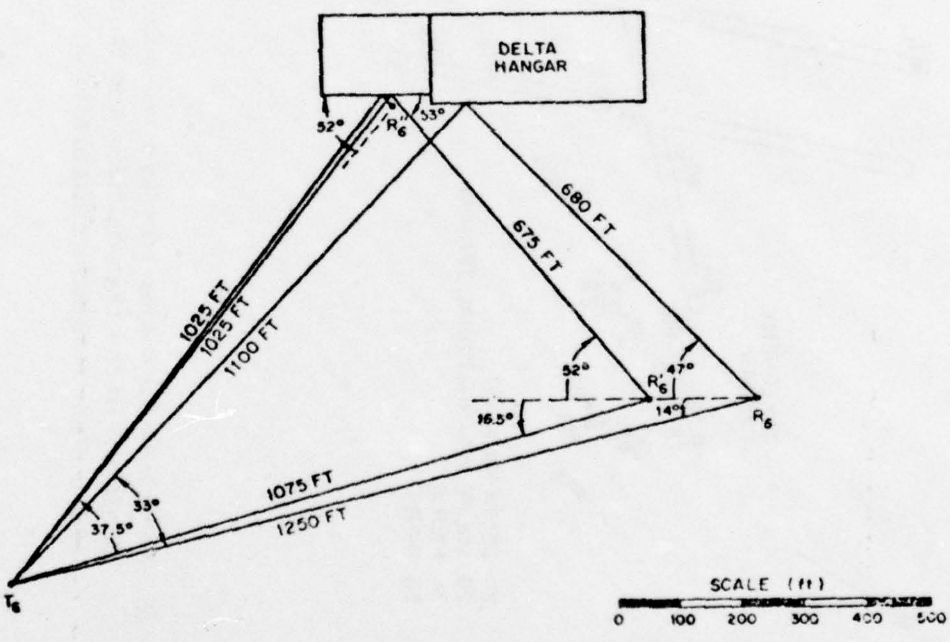


Figure 21. Geometry for the measurements on the Delta Airlines hangar.

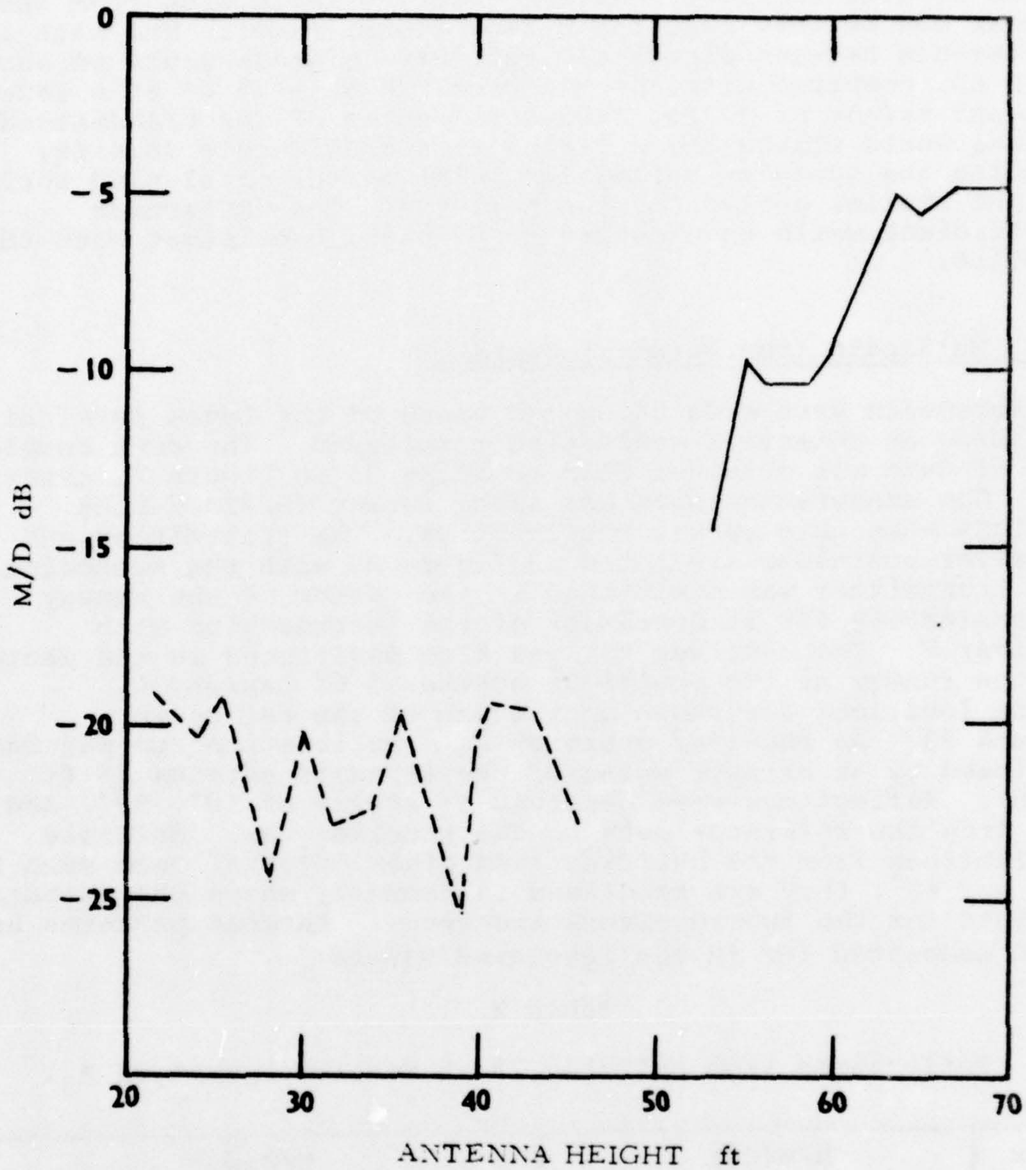


Figure 22. Multipath to direct (M/D) signal ratio versus receiver antenna height for the reflections observed from the Delta Airlines hangar.

These results indicate that the observed reflection from the hangar can be very near the direct signal level. The path loss difference between direct and reflected signals would be about -4.0 dB, compared with the measured M/D of -4.5 dB at a receiving antenna height of 70 ft. The beam center of the transmitted signal would strike the building at approximately 38.6 ft, placing the specular reflection point on the metal-clad surface of the smaller portion of the building. The reflection coefficient would be expected to be high, consistent with the results.

4.2 Multipath from Terminal Building

Measurements were made using two piers of the Logan terminal building as potential reflecting structures. The most complete set of data was obtained from building 33 in figure 20 (Pier C). One measurement path was along runway 4L/22R during periods when this runway was inactive. The transmitter and receiver positions are noted in figure 20 with the subscript 3. The transmitter was positioned in the center of the runway approximately 400 ft northwest of the intersection with taxiway F. The receiver van was also positioned in the center of the runway at two positions southeast of taxiway C. These locations are shown on the map of the region in figure 23. At receiver position R_3 a calibration run was made, followed by an azimuth swing of the transmit antenna (6 ft dish). Reflections were observed at angles of 58°, 59°, and 60° from the reference path to the receiver van. Multiple reflections from the building (and other objects) were seen at 59° and 60°, they are tabulated in table 2, where the antenna heights for the two receivers are given. Antenna patterns have been accounted for in the tabulated values.

Table 2

Reflections from building 33 at receiver position R_3.

Tx Ant. Azimuth	M/D(dB) Reclections Chan. No.1 Ant. ht. = 42 ft			M/D(dB) Reflections Chan. No. 2 Ant. ht. = 65 ft			
	r_1	r_2	r_3	r_1	r_2	r_3	r_4
60^o	-15.8	-18.6	-22.6	-14.0	-19.0	-20.4	-24.0
59^o	-19.4	-17.0		-18.2	-15.8		
58^o	-16.0			-13.2			

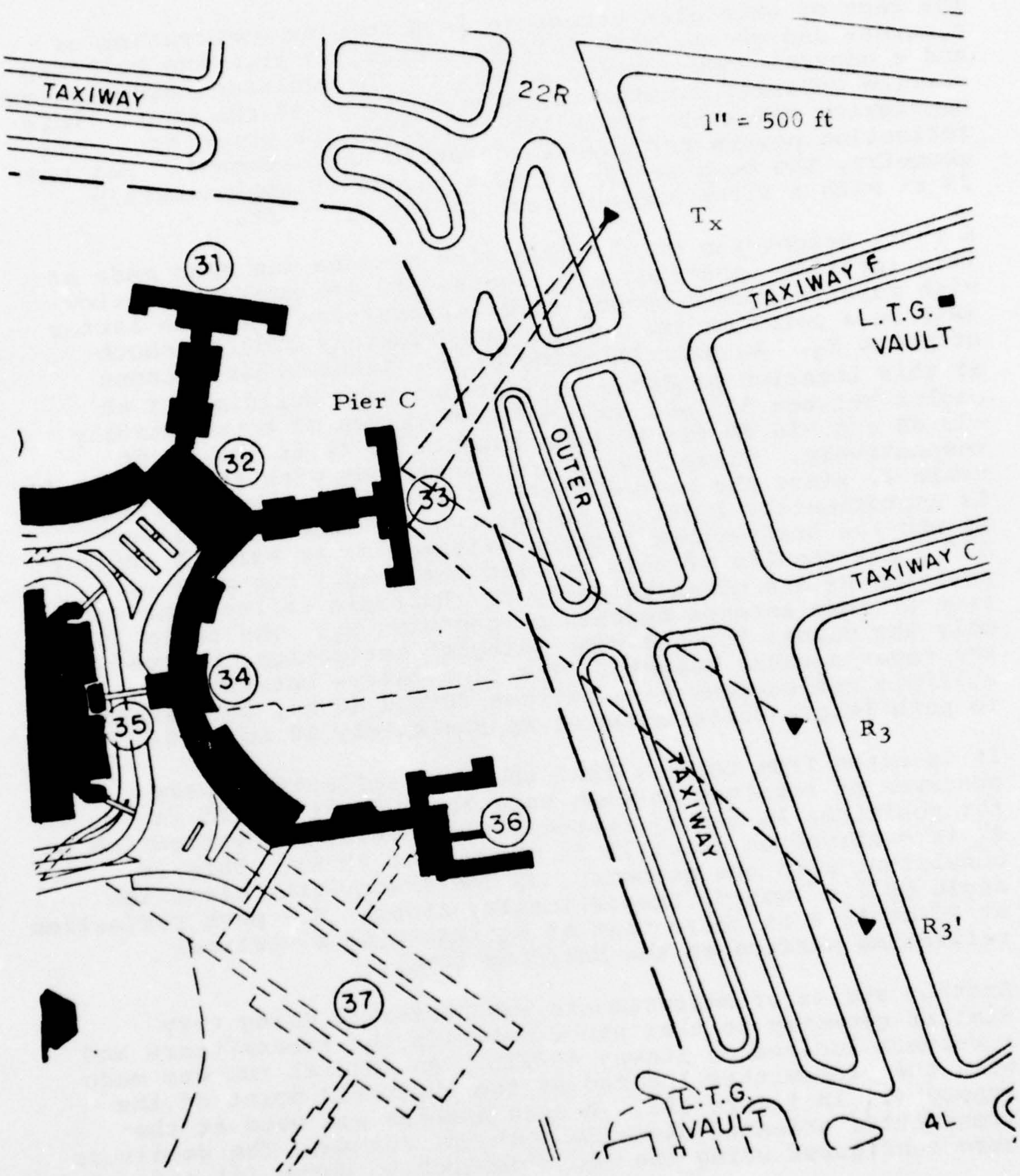


Figure 23. Map of the terminal building area and runway 4L/22R, showing geometry for tests involving Pier C (building 33).

The face of this pier structure is a complex combination of concrete and glass, with jetways protruding from the building and a control tower rising above it. In addition, aircraft and service vehciles clutter the area in front of the pier. This complexity makes it impossible to define the specular reflection points for any of the above measurements. For the geometry, the beam center is at a height of approximately 39 ft with a first Fresnel zone radius of 11 ft.

A short height-run on the receiving antenna was also made at this location (position R_3); these data are presented below with results from a second receiver position R_3'. The latter (R_3') is a point on the runway approximately 1200 ft south of point R_3. An azimuth swing of the transmitter antenna at this location produced reflections from building 33 at angles between 51° and 53° with M/D values of approximately -19 dB and -16 dB for antenna heights of 42 ft and 65 ft respectively. These levels are consistent with those given in table 2, since the path-differential loss for the reflection is approximately 2 dB. A height run was made at position R_3' wth the transmitter antenna oriented at an azimuth angle of 53°. The results of this run and the height run made at position R_3 are given in table 3. Multiple reflections were seen at some antenna heights at position R_3. The table lists only the values for the same (single) reflection observed at the tower antenna heights. The time delays between the multiple reflections were between 20 and 40 ns, corresponding to path length differences of approximately 20 to 40 ft.

It is noted from table 3 that the peak reflections were observed at receiver antenna heights of 30 ft and 45 ft for positions R_3 and R_3' respectively. Thus, the reflection at R_3' is observed at about 15 ft above that at R_3. This is consistent with the geometry, as the transmitter elevation angle of 1.6° would, theoretically, result in a peak reflection at R_3' at 16.8 ft above that at R_3 (assuming a vertical reflecting surface at the building face).

Another series of measurements was performed using very similar geometry to that above but with the transmitters and receivers located on runway 4R/22L. An initial run was made with the transmitter located at the threshold point of the runway (T_1 in figure 20). A horn antenna was used at the transmitter oriented directly down the runway. The receivers were configured using the two side-looking horns (a) and (c) in

figure 12. Calibrations were made with the van several hundred feet from the transmitter, and the van was then driven the full length of the runway. Receiver gain adjustments were made along the route to account for distance losses. No significant reflections were observed during the run. The result is consistent with simple geometric considerations, as the latter would predict the main reflection (if any) to come from building 33, and to be received at a point off the south end of the runway.

Following the above run, the transmitter was moved to position T_2 in figure 20. This point is midway between the intersections of 4R/22L with runways 15R/33L and 15L/33R. The receiver van was first located at position R_2' in figure 20, which is near the intersection with the STOL 18/36 runway. An

Table 3

Height runs for receiver positions R_3 and R_3'.

(Transmitter at location T_2; Reflections from building 33)

Receiver Ant. Height (ft)		Maximum M/D(dB) Receiver Position R_3			Receiver Position R_3'		
Chan. 1	Chan. 2	Chan. 1	Chan. 2	Multiple Reflect.	Chan. 1	Chan. 2	Multiple Reflect.
22	47	-14.7	-11.0	No			
26	51	-16.6	-11.0	No			
30	55	-13.2	-10.6	No			
36	61	-16.7	-13.0	Yes			
40	65	-15.6	-13.8	Yes	-23.1	-19.5	No
45	70	-19.4	-18.3	Yes	-17.7	-18.7	No
47	72				-20.7	-20.3	No

azimuth scan of the transmitter antenna over 70° toward the terminal buildings did not produce any measurable reflections at this location with the receiver antennas at 40 ft in height. The geometry for this and subsequent tests is sketched in figure 24. It can be seen that position R_2 is not an ideal location for reflections from the terminal building area. Angles are not proper for Pier C, and other building surfaces would be marked by the pier structures. No reflections were observed at this location. The transmitting antenna was then pointed (optically) toward Pier C at an angle of 60°, and the receiver van driven along runway 4R/22L to a point near the threshold for 4R. Reflections were observed at this point, and the geometry indicated in figure 24 shows them to be coming from the Pier C area (building 33). An azimuth swing of the 6 ft dish at the transmitter produced reflections at angles of 58° through 63°, with a maximum at an angle of 61°. The measured impulse function displayed multiple reflections at all angles, with four distinct paths seen for the response at 61°. A sketch of the response at both 60° and 61° is shown in figure 25 (Shnidman, 1975), and the time delay for the reflected signal relative to the vestige of the direct signal is seen from the figure. The small reflection seen in the upper trace of figure 25 at a delay of about 1200 ns was attributed to an aircraft on taxiway F near the intersection with runway 4L/22R (Shnidman, 1975). The peak M/D for each angle is given in table 4, as measured with a receiver antenna height of 42 ft.

Table 4

Reflections from building 33 at receiver position R_2.

Tx Antenna Azimuth	M/D (dB) Aircraft Reflection	M/D (dB) Building 33 Reflection (max.)
58°	-27.5	-27.5
59°	-26.5	-25.5
60°	-32.0	-20.0
61°	-	-18.5
62°	-	-21.5
63°	-	-30.0

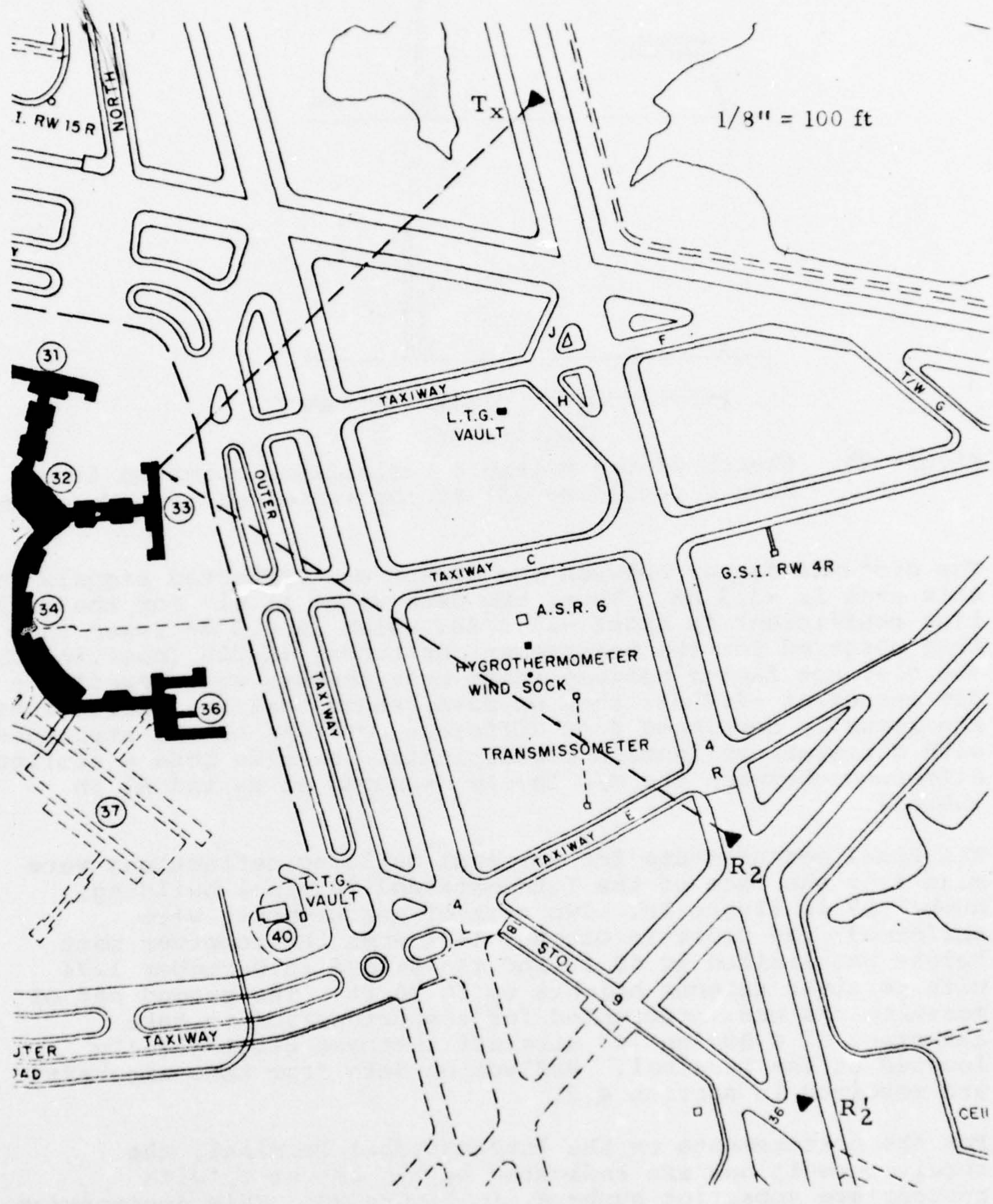


Figure 24. Map of the terminal building area and runway 4R/22L, showing geometry for tests involving Pier C (building 33).

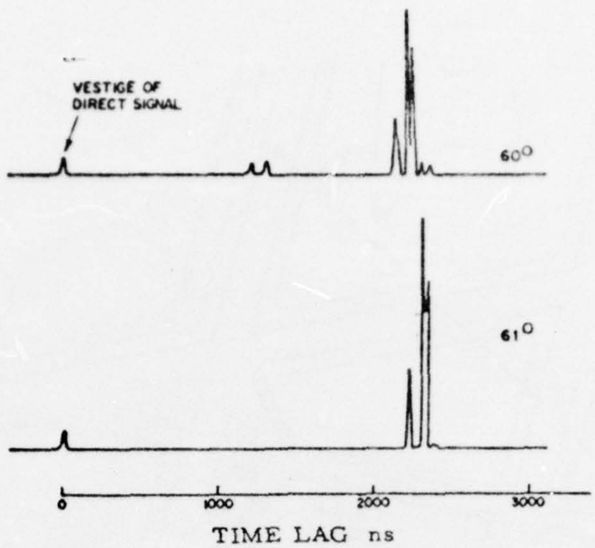


Figure 25. Sketch of the multiple reflections observed from Pier C (building 33) at the indicated azimuth angles.

The distance factor between the direct and reflected signals for this case is -3.2 dB. Thus, the peak value at 61° for the reflection coefficient is about -15.3 dB, which is 4.3 dB lower than that observed for the measurement on runway 4L/22R (position R_3). The distance factor between these measurements would predict a difference of -8.8 dB; then we must assume that the reflections are actually developed from different portions of the structure with different reflection coefficients. We also note a similar difference between the M/D levels measured at R_3 and R_3' in table 3.

The final measurements for terminal building reflections were made from the face of the International Terminal building, number 29 in figure 20. Two sets of measurements were performed; the first in October 1974 when the receiver mast height was limited to 50 ft and the second in December 1974 with receiver antenna heights up to 70 ft. The second set of measurements was interrupted for a short period to take advantage of a Boeing 747 aircraft that was strategically located at the terminal. Reflection data from this aircraft are reported in section 4.2.

For the measurements on the International Terminal, the receiver positions are indicated by the letter I, with appropriate subscript numbers, in figure 20. This designation is used to alleviate possible confusion with other configurations. The transmitter location was fixed in all

cases at a position T_5, which is located behind the Glide Slope Indicator (GSI) for runway 15R. This position is adjacent to the intersection of the runway with the north taxiway, and is shown in the area map of figure 26. Receiver locations ranged from positions directly in front of the terminal building on the parking apron, to several points along the outer taxiway in front of the building, and along an extension of this line down the access taxiway (used by Allegheny Airlines).

The geometries for the initial series of tests are sketched in figure 27 (Shnidman, 1975). As noted in this figure, the terminal building has four large jetways protruding from the building that can assume different angles with respect to the building face. In addition, the building has a large tier section on the top with a much less cluttered surface than the lower part of the building. These factors make it impossible to describe the actual specular reflection points on the building. However, at each measurement point the telescope mounted to the transmitter antenna was used to optically locate the possible reflecting region. These points ranged from sides of the jetways to the building face itself.

The transmitter antenna was fixed at an elevation angle of 1.6° for each run. Thus, for the distances seen in figure 27, the transmitter beam center should be between 48 ft and 59 ft high at the building surface. The corresponding first Fresnel zone radius would be on the order of 12 to 15 ft. Some of the reflections seen from the building were multiple reflections due to the complex structure. Only the largest of the secondary reflections were analyzed. The results of the initial tests are tabulated in table 5.

Since the transmitter was positioned close to the present Glide Slope Indicator for runway 15R, the test geometry was very realistic for a MLS installation on this runway. The measurements made from the outer taxiway (parallel to 15R/33L) at the mast heights available for the receiver locations could reasonably be extrapolated to the runway, and closer to decision heights pertinent to approach situations for this runway. These extrapolations were made by Shnidman (1975), and the calculated error for approach angle and doppler effects were determined to be "large enough to be of concern but sufficiently small that they should not cause serious

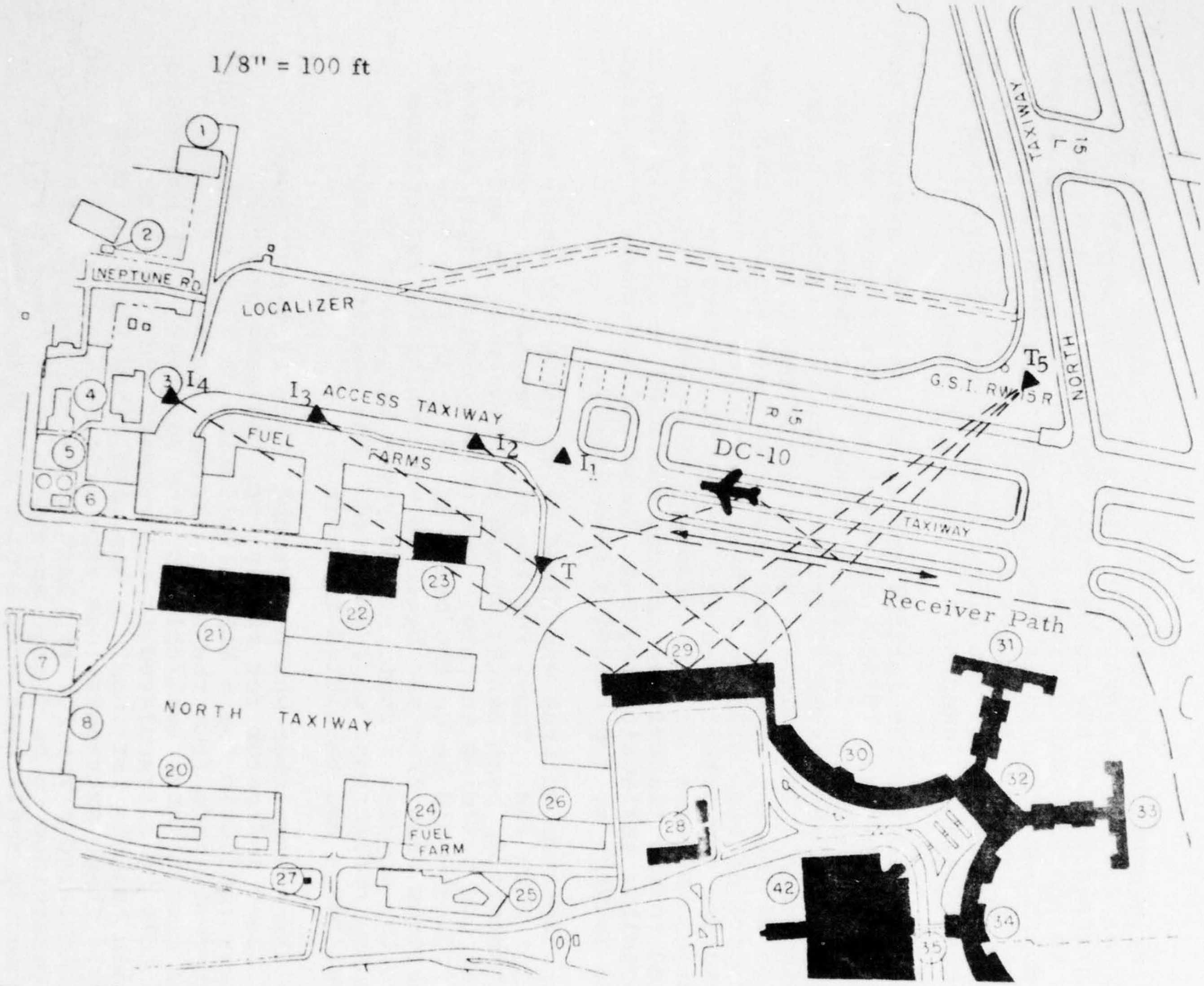


Figure 26. Area map showing locations for measurements involving the Volpe International Terminal Building and a DC-10 aircraft.

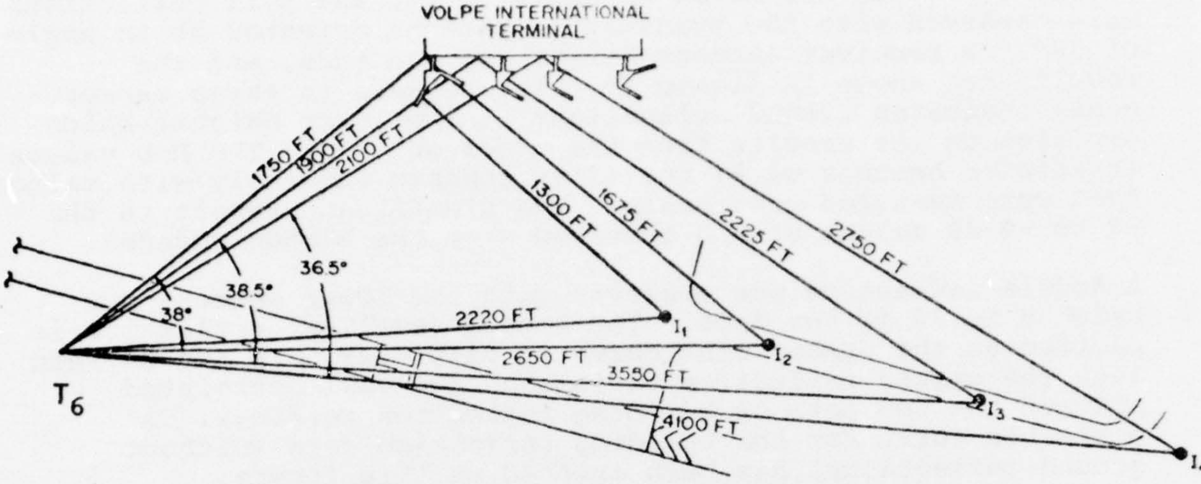


Figure 27. Approximate geometry for measurements on the Volpe International Terminal.

problems". Details of these calculations may be found in the reference, and are not repeated here. The maximum M/D found from these measurements was the -17 dB value noted in table 5, for position I_3 at an antenna height of 40 ft. However, Shnidman speculated that this value could be as high as -6 dB for his calculations. The latter value is verified in a subsequent measurement reported below.

During the December 1974 period, the receiver mast extension permitted antenna heights of slightly over 70 ft as noted previously. Measurements from the International Terminal were repeated for receiver positions at I_2, I_3, and I_4, and additional measurements were made at positions I_5, I_6, and I_7. These locations are shown more precisely in figure 28. At position I_2, a single reflection was seen on both the upper and lower probe antennas at a transmitter angle of 38° toward the terminal. The lower antenna, at a height of 45 ft measured the M/D at -11 dB which is comparable to the previous observation in table 5. The upper antenna (70 ft) measured the M/D = -27 dB at this angle. However, the peak value at this antenna height was observed at a transmitter angle of 40° and at -13 dB. Since the reflections were not from the same point on the building, no further measurements were made in this location.

The receiver van was moved to position I_3, and peak reflections were observed with the transmitter antenna oriented at an angle of 38°. A receiver antenna height run was made, and the results are shown in figure 29. The pattern in these measurements indicates ground reflections at the lower heights which diminish in the results from the upper antenna. The M/D values at antenna heights of 27 and 47 ft compare favorably with values that were measured previously. The significant result is the -7 to -9 dB values of M/D observed with the higher antenna.

A double reflection was observed with the lower antenna for heights to 30 ft for data. The second (smaller) reflection is plotted as the dashed line curve in figure 29. It can be seen that the ground reflection variations are well correlated between the two sets of building reflection readings. A plausible curve for the building reflection data (without ground reflections) has been drafted on this figure.

Table 5

Summary of data for the international terminal.
(October, 1974)

Receiver Van Location	Transmitter Antenna Angle (degrees)	Receiver Antenna Height (ft)	M/D (dB)
I_2	40	22	-18
I_3	40	40	-17
I_4	38	40	-18

Transmitter was located in position T_5.

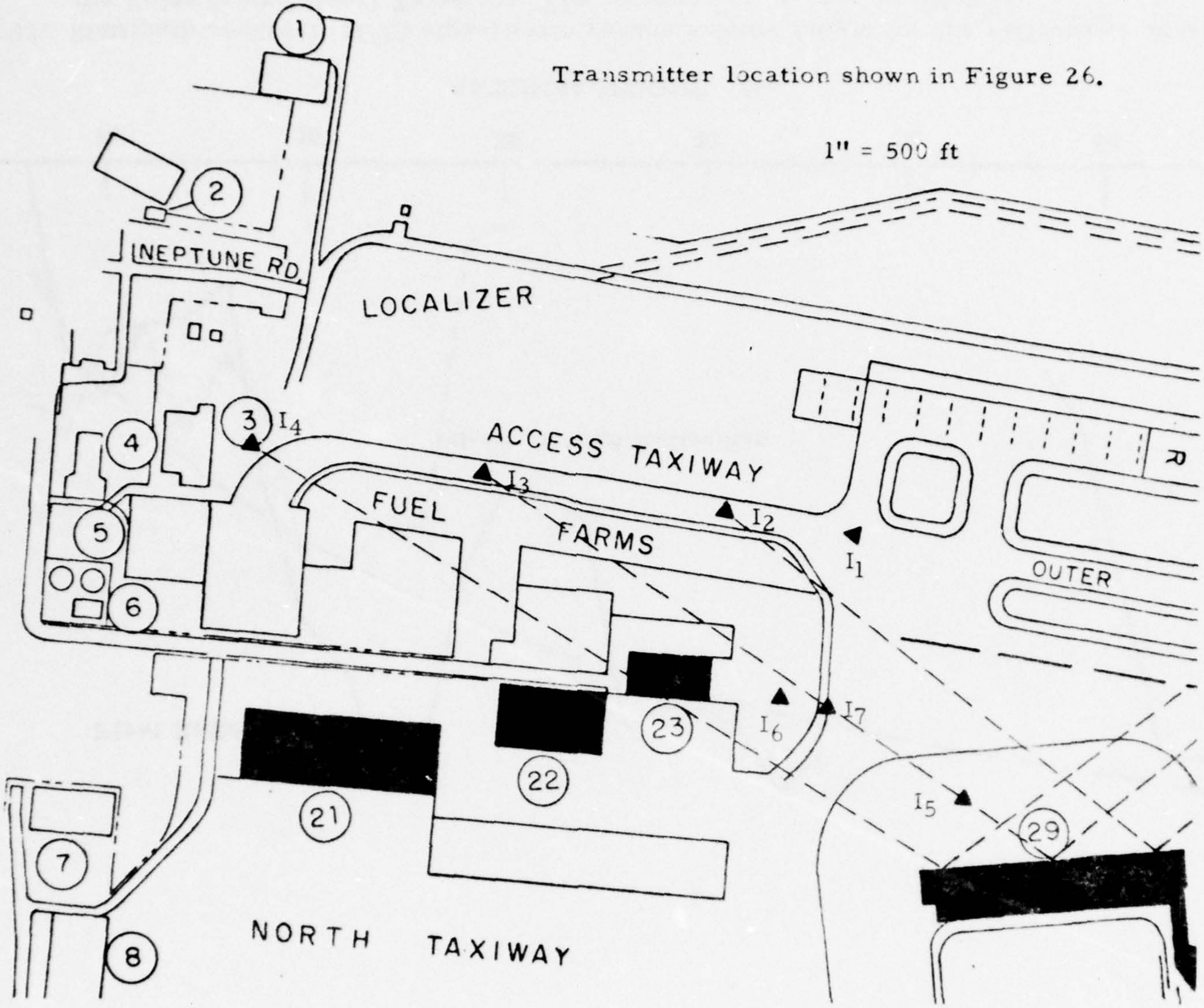


Figure 28. Receiver van locations for all measurements involving the Volpe International Terminal Building (No. 29).

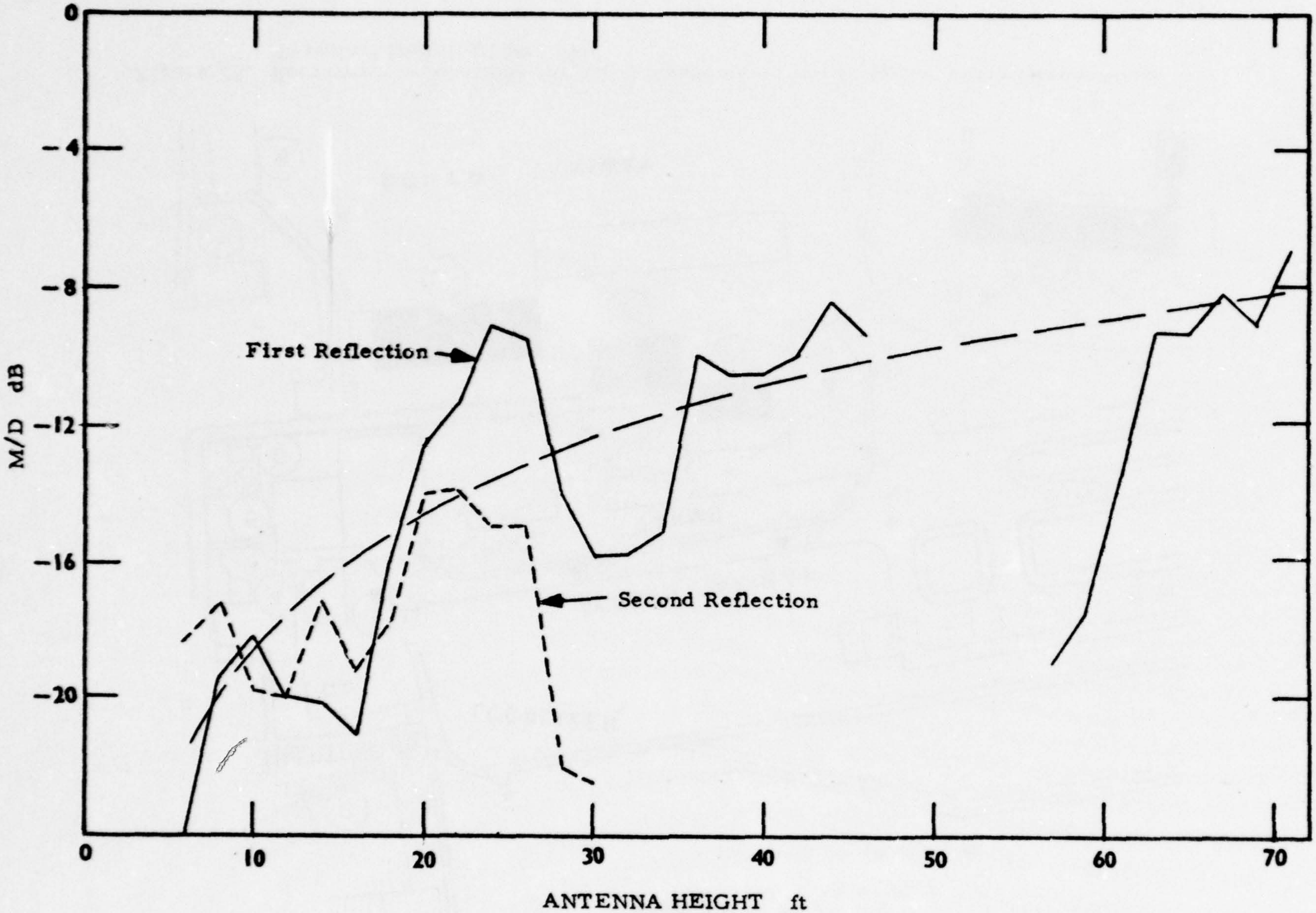


Figure 29. Multipath-to-direct (M/D) signal ratio versus antenna height for the reflections observed from the Volpe International Terminal. The receiver van was in position I_3.

While in position I_3, a special run was made as a check on the later applications of the antenna patterns in the data analysis. The receiving antenna for channel two of the probe was switched to the rear-looking horn at the same height as the side-looking horn used on channel one. The pattern loss for channel two in the geometry should be 3.1 dB with respect to channel one (30° angle difference). In addition, the change in the relative height with respect to the transmitter antenna main beam would cause a loss in the direct (reference) signal level on channel two of approximately 1 dB. Thus, the reflection data on the two channels should be very comparable, with channel one measuring M/D values 2 dB higher than channel 2. The reflection responses were identical in shape in each instance, and an average of six readings at different heights results in a ratio of 1.97 dB with a standard deviation of 0.6 dB. These results indicate the relative accuracy of applying the antenna pattern corrections to the measured data.

The final measurement point along the access taxiway was position I_4, at the end of the taxiway on the apron in front of the Massport maintenance building No. 3. The receiver antenna heights were near the maximum values of 45 ft (channel one) and 70 ft (channel two) at this position. An azimuth swing of the transmitter antenna was made in 1° steps from 40° to 32° toward the International Terminal. Multiple reflections dominated and the level of the two most significant are given in table 6. We note that the maximum result on the lower (channel one) antenna at -36° azimuth from the transmitter is very comparable to that measured at position I_3 (see figure 29). The optical view from the transmitter antenna indicated that the first reflection surface was the jetway ramp No. 5 jutting to the front of the building. This suggests that the second reflection was from the building proper. The path difference (as measured by the probe in time delay) was on the order of 88.6 ft.

Table 6

Data from international terminal with receiver van at position I_4.

(Azimuth swing of transmitter antenna)

Transmitter Antenna Angle (degrees)	M/D (dB) Lower Antenna r_1	Lower Antenna r_2	Upper Antenna r_1	Upper Antenna r_2
-40	**-35.5**	**-35.9**		
-39	**-31.4**	**-33.0**		
-38	**-17.3**			
-37	**- 8.7**	**-10.9**	**-25.4**	**-23.4**
-36	**- 7.9**	**-13.9**	**-21.6**	**-21.6**
-35	**- 8.1**		**-19.4**	**-27.4**
-34	**-16.1**	**-17.5**	**-18.6**	**-26.4**
-33	**-13.9**		**-18.0**	
-32	**-18.1**		**-21.2**	

Receiver positions I_5 and I_6 shown in figure 28 were used to find a location along the reflection radial from the building to position I_3, in order to make an additional height run closer to the terminal building. Spot measurements were made at each location, and then the van was moved backward from I_6 until a peak reflection reading was obtained at position I_7. The transmitter antenna was oriented at 38° toward the terminal building; the same azimuth orientation used with respect to position I_3. The results of the antenna height run are plotted in figure 30. Ground reflection lobing is noted, however the reflection data above 60 ft in height are seen to be fairly smooth with relatively high M/D of -7 to -8 dB. These values are comparable to those measured at position I_3. They also confirm the values used in the MLS error calculations made by Shnidman (1975).

4.3 Multipath from Aircraft

A number of test configurations were used at Logan International Airport to measure reflection data from aircraft, particularly those in the "large-body" class such as the Boeing 747 and the Douglas DC-10. The first measurement was made during the October tests using a DC-10 aircraft through the courtesy of Eastern Airlines. The measurements were made at night during a period when runway 15R/33L was inactive. The aircraft was towed to a center line position on the outer taxiway, with the nose heading west and the tail section about 200 ft from the end of the median strip between the outer and inner taxiways (see figure 26). The transmitter was located on the edge of the ramp in front of the International Terminal, on a center line for the end of building No. 23. The receiver van was driven along the inner taxiway from a calibration point opposite the threshold mark for 15R to a point about 200 ft beyond the NE corner of terminal building No. 31 (Pier B). The transmitter antenna pointed (optically) toward both the tail section and fuselage of the aircraft. The receiver antenna height was 50 ft for the runs. The maximum reflection from the aircraft was observed from the tail section at a van position about 700 ft from the west end of the median strip. Positions were recorded with reference to marking lights at the edge of the taxiway. However, due to the shape of the aircraft and the

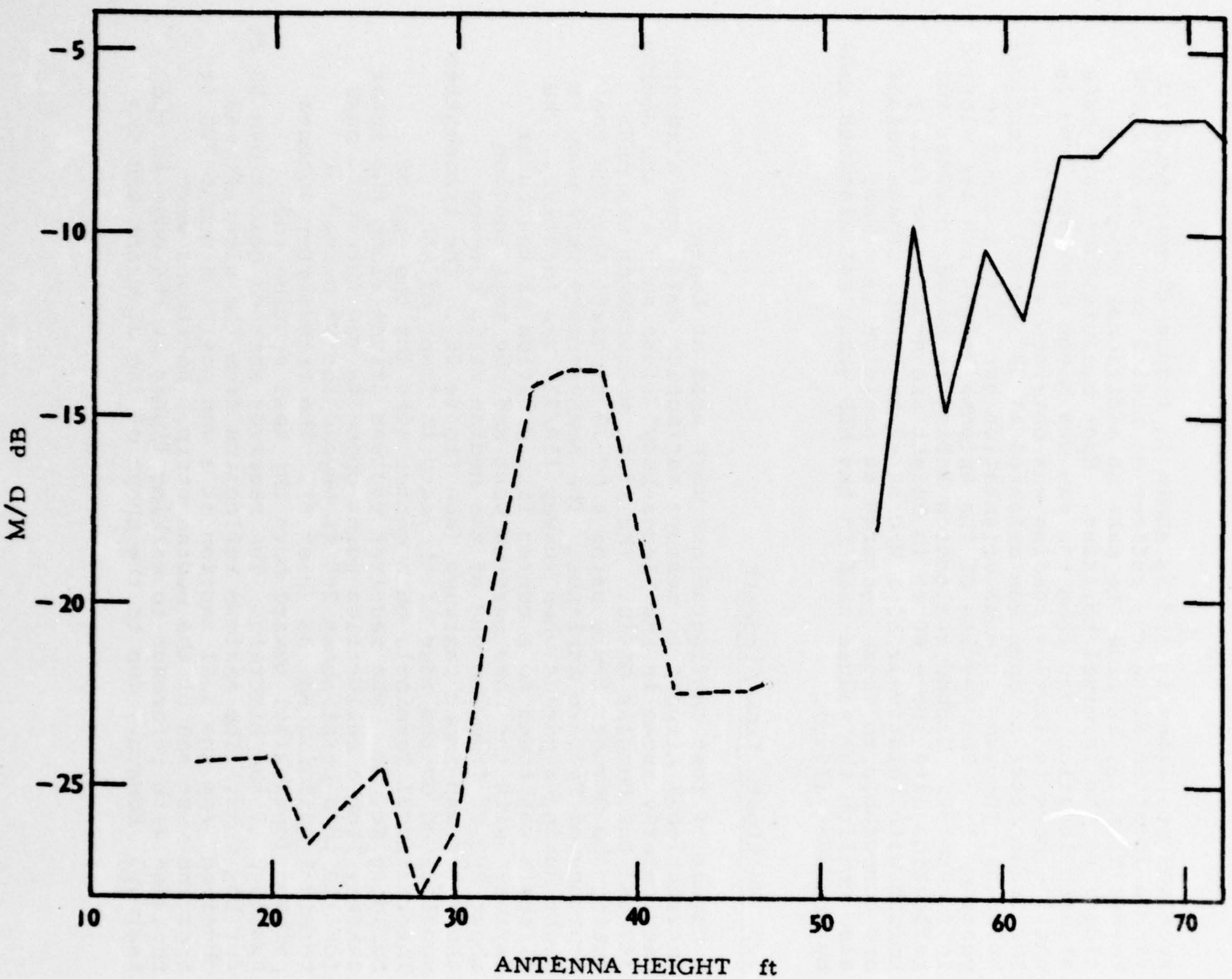
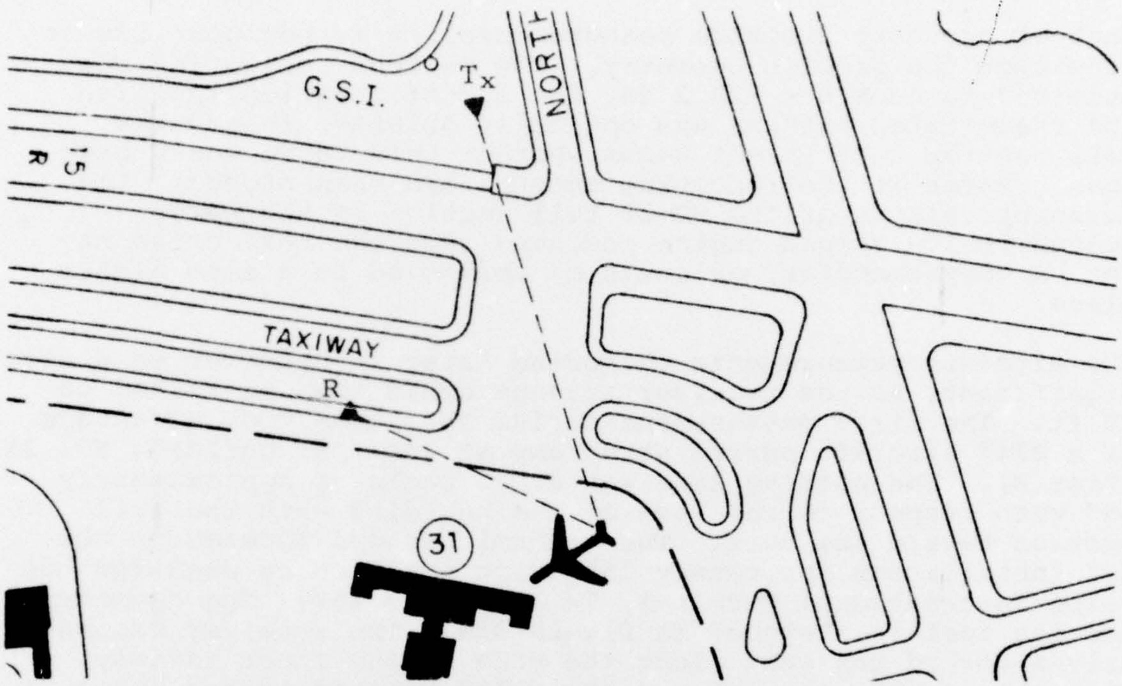


Figure 30. Multipath-to-direct (M/D) signal ratio versus antenna height for the reflections observed from the Volpe International Terminal. The receiver van was in position I_7.

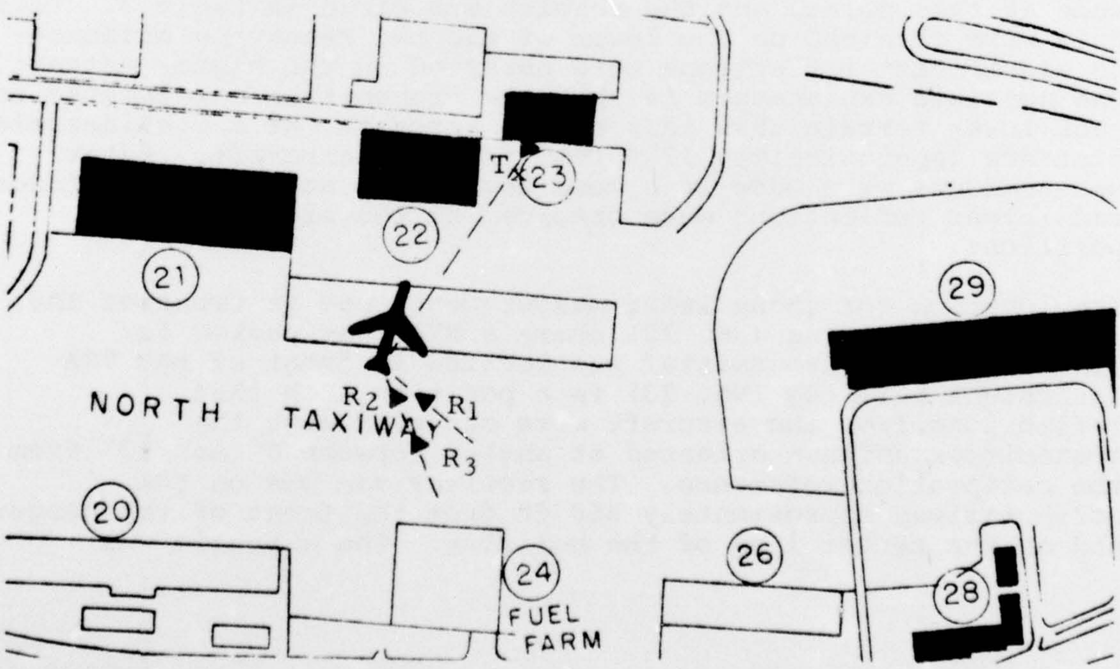
lack of accurate distance measurements, it is not possible to construct the precise geometry. The maximum reflection was observed to be M/D = -29.2 dB, for a confifuration in which the transmitter antenna was optically oriented toward the tail section. It is not known whether this value would have been greater if the receiving antenna had been higher. The dominant feature of the DC-10 tail section is the large cylindrically shaped engine pod, and thus the reflection may not be very specular, or could be reflected to a much higher plane.

The aircraft measurements performed later in December were more significant, as the receiver antenna could then be raised to 70 ft. The first measurement during this time took advantage of a B747 aircraft parked at a ramp at terminal building No. 31 (Pier B). The parking line was at an angle of approximately 45° with respect to the face of the building with the tail section toward the east. The transmitter was located at the GSI installation for runway 15R (same position as used for the Volpe International Terminal, T_5 in figure 26). The geometry for the test is sketched in figure 31a. The receiver van was driven toward the west along the edge of the inner taxiway. With the transmitter antenna optically pointed toward the tail section of the aircraft (31°), a receiver point was selected that registered the maximum reflection. A mast height run was made at this point, and the results are given in table 7. These data were obtained on the lower of the two receiving antennas; no significant reflections were observed on the higher antenna. One possible explanation is that the transmitter was located on much lower terrain than that at the aircraft, at a considerable distance (approximately 1350 ft), from the aircraft. Later measurements were made in a more level area at shorter distances, and larger reflections were observed at the higher antenna positions.

The location for these later measurements was in front of the TWA hangar building (No. 22) where a B747 was parked for servicing. The transmitter was located in front of the TWA airfreight building (No. 23) in a position such that reflections from the aircraft were observed with the transmitter antenna oriented at angles between 6° and 12° from the calibration reference. The receiver van was on the north taxiway approximately 550 ft from the front of the hangar and on the center line of the building. The aircraft was



(a) October measurements.



(b) December measurements.

Figure 31. Measurement locations for tests on a B747 aircraft.

Table 7

Reflection data form tail section of B747 aircraft.

Receiver Antenna Height (ft)	M/D (dB)
47	-24
44	-19.6
42	-22.6
40	-18.6
38	-22.8
36	-16.8
34	-22.6
32	-16
30	-16.8
28	-16.6
26	-15.8
24	- 5.2
22	- 7.4
20	-15.4

parked with the nose toward the hangar, angled at about 15° with respect to the hangar. The tail section was slightly to the west of the center line, and out approximately 465 ft. These locations are noted in figure 31b. During an azimuth swing of the transmitter antenna, reflections that appeared to be from the windshield of the aircraft were observed. A height run on the receiving antennas was made with multiple reflections recorded that ranged from -32 dB to -45 dB, with the peak value observed at an antenna height of 65 ft. These reflections were quite small probably due to the low reflection coefficient expected for the windshield material. In addition, small reflections from the body of the plane were seen but were not significant. Reflections from the tail section however were significant, as expected since the receiver van was located at an optimum distance and on a radial that gave peak reflection values. The incidence angle in the configuration was approximately 20° and the reflection angle was estimated at 35°; a result of the curvature of the tail section itself. A height run was made with the van located about 200 ft (position R_3 in figure 31b) from the aircraft tail on the radial noted above. The results of this run are plotted in figure 32. Note that the maximum M/D values were observed with the receiving antenna between 40 and 50 ft. Although there is evidence of some ground reflections these reflections appear small over the height range of 40 to 55 ft. It was necessary to make careful antenna pattern adjustments to these data because of the geometry. We note two data points from the upper antenna show a positive M/D value, but they are assumed to be within the accuracy possible in the case of ground reflection and pattern uncertainties. The significant result is that the reflections from the aircraft tail section can quite readily approach the direct signal level, and are observed at points higher than the tail section due to the angle of the vertical structure.

The final measurements made on aircraft were those for the Boeing 727 perhaps the most common aircraft to be found at commercial terminals today. The Lockheed L1011 aircraft is also used extensively and resembles the B727 in structure, as both have an engine pod as an integral part of the tail section. The geometry for this experiment was restricted, and thus distances are short. The aircraft was parked in front of the Eastern Airlines hangar (Bldg. No. 39) in the south taxiway area. The aircraft was on a line parallel to and

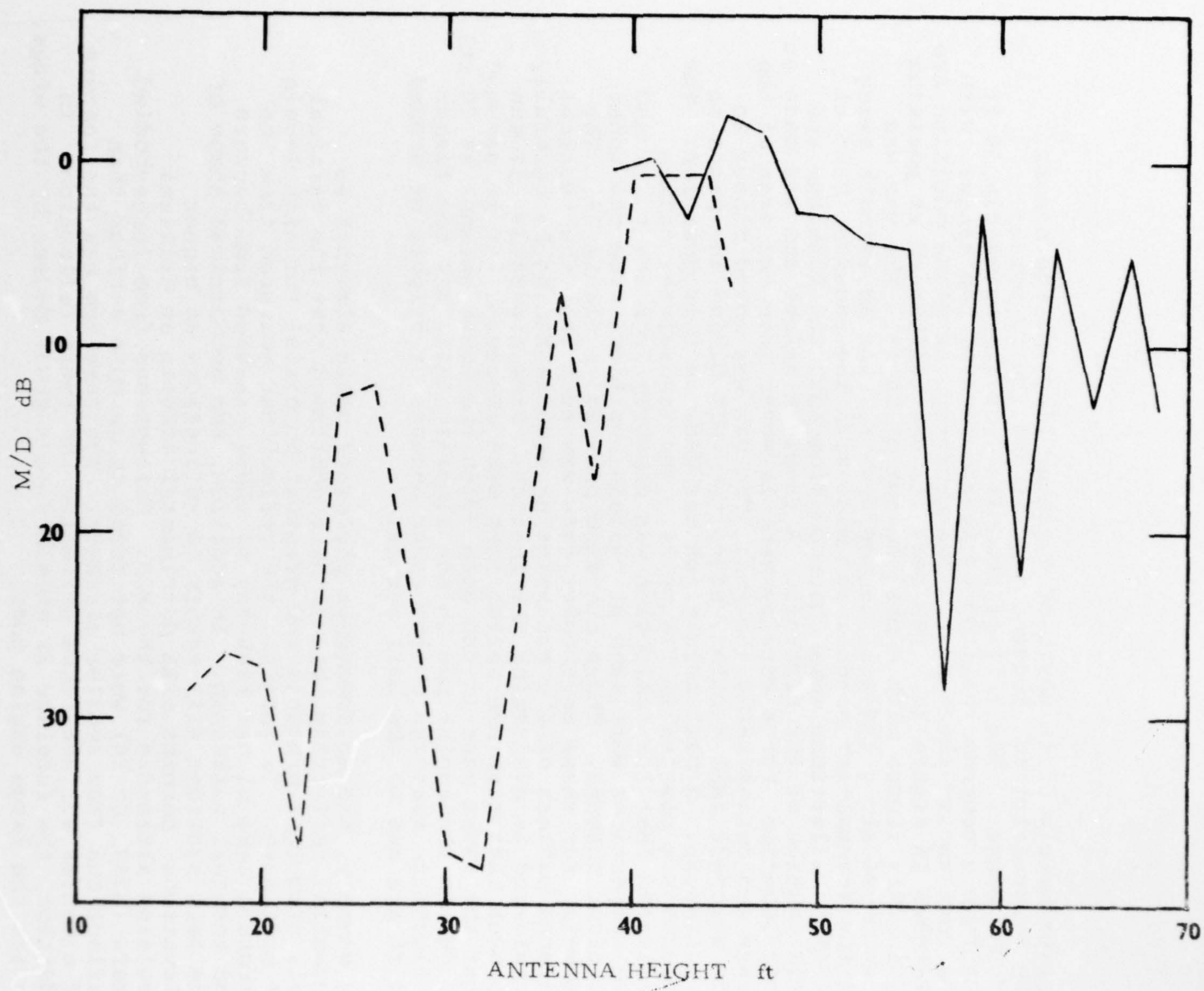


Figure 32. Multipath-to-direct (M/D) signal ratio versus antenna height for the reflections observed from the tail section of a B 747 aircraft.

approximately 62 ft north of a center line for the hangar. The transmitter was located just off of the SE corner of the hangar. The tail of the plane was approximately 50 ft out from a concrete wall opposite the face of the hangar, with the nose toward the hangar. The geometry and plane position are sketched in figure 33. The receiver was calibrated at position R_0 in this figure with a mast height of 20 ft. The van was then moved along the wall to position R_1, and an azimuth swing of the transmitter antenna was made with the receiver mast at 40 ft. Reflections were observed from both the fuselage and tail section of the aircraft. A receiver height run was made at this location, but a service vehicle moved into the area of the plane and contaminated the run. The van was moved closer to the aircraft tail section, along the wall behind the plane to position R_2. A mast height run was made in this position. The results are plotted in figure 34. The transmitter optics indicated that the reflection was directly from the tail, and two reflections were seen at certain positions from the upper receiver antenna. These are also plotted in figure 34. The geometry for these particular data was such that the vertical antenna pattern of the transmitting antenna had to be carefully considered in evaluating the results. From figure 34, it can be seen that high M/D reflections were observed. It is assumed that the first peak in the data (with the lower antenna at 20 ft) is due to the engine pod in the aircraft tail, and the larger reflections measured on the upper antenna at heights of around 40 ft are due to the tail itself.

In summary, the measurements performed using aircraft as potential reflecting objects have confirmed that the vertical tail structure presents the greatest potential for high levels of multipath. In general, the reflections measured from the aircraft were higher than any of those measured from hangars and terminal buildings. In addition, the geometrical shape of the tail sections will result in reflections at higher elevations; perhaps with detrimental effects at critical decision altitudes for the MLS. Reflections from large-bodied craft (B747, DC-10) were not found to be more serious than reflections from smaller aircraft. The fuselage has the feature of a convex surface, thus diffusing the radio reflection. In addition, the fuselage is shielded to a great degree by the wings, as are the large engine pods.

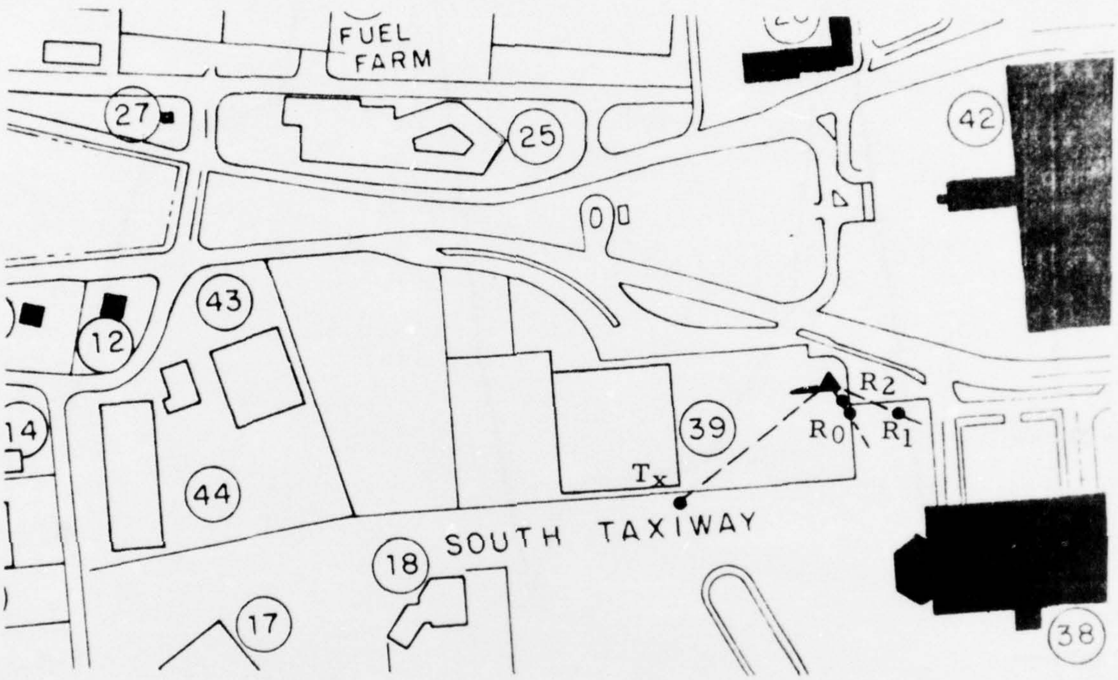


Figure 33. Location and positions for measurements on the B727 aircraft.

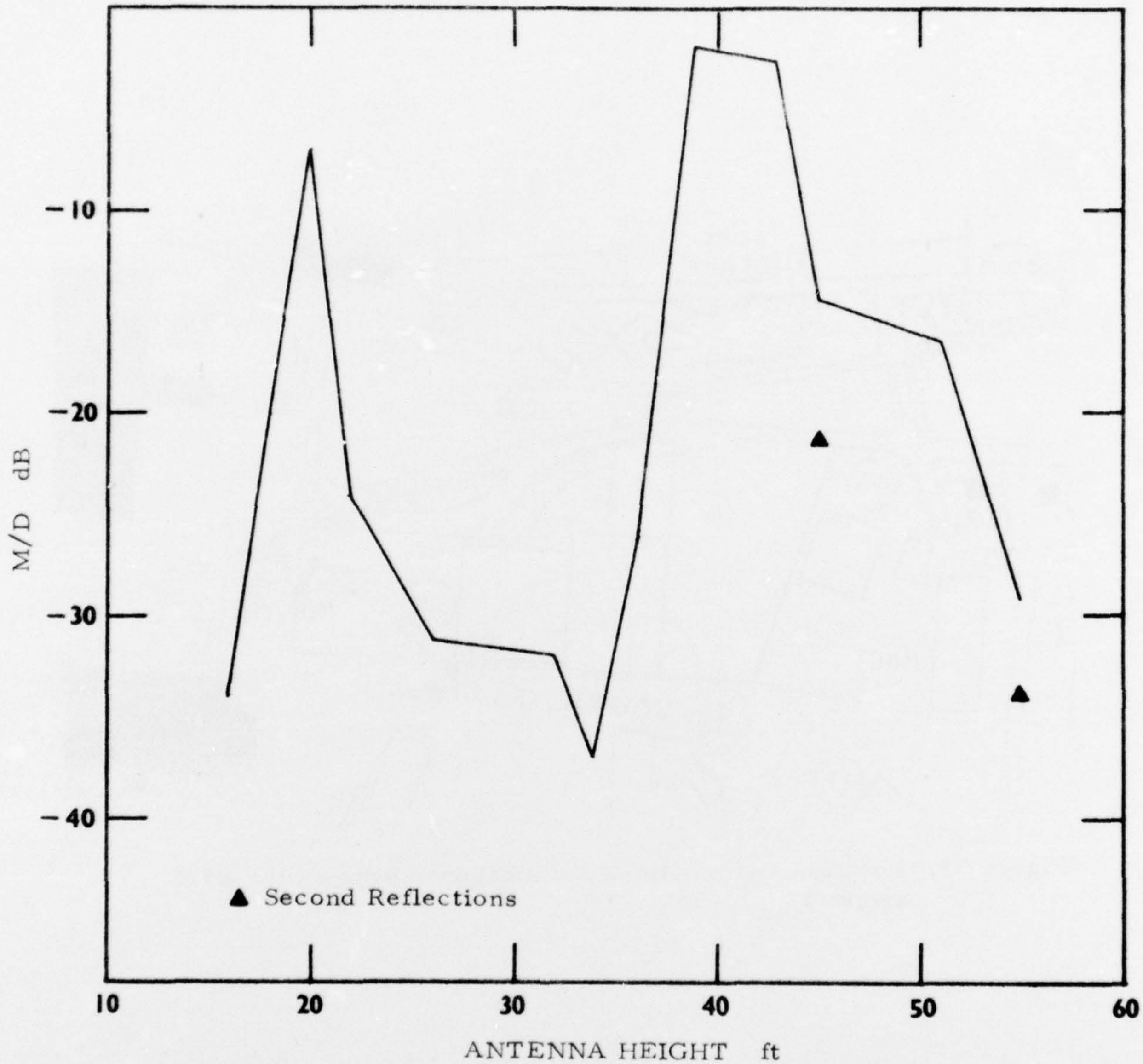


Figure 34. Multipath-to-direct (M/D) signal ratio versus antenna height for the reflections observed from the tail section of a B 727 aircraft.

5. CONCLUSIONS

This report has described the equipment and methodology for obtaining measures of potential multipath signals found in operational airport environments, that could be critical to the performance of MLS. The geometries for the various parts of the total experiment were chosen to be as realistic as possible relative to an actual MLS installation. The major limitation in this regard was the maximum receiving antenna height of 70 ft. This is considerably lower than the decision heights associated with MLS, but the results obtained at this height illustrate that the multipath could be significant when extrapolated to the decision points.

Basically, three areas of concern in the airport environment were investigated independently. These were large hangar buildings, terminal buildings, and aircraft on the surface. The results of the experiments have shown the following:

1. Significant reflections can be observed from the hangars, terminal buildings, and other structures at an operating airport.

2. Multiple reflections occur frequently due to building clusters and complex structural surfaces.

3. Potential reflecting structures are located in positions relative to active runways, so that the reflections can become a multipath problems at MLS decision points.

4. Aircraft on the ground, either parked or taxiing, present the most significant reflecting surface to MLS signals.

The measurements performed in this experiment were made possible by application of a psuedo-random noise (PN) probe technique developed at ITS. The primary feature of the system is the ability to observe a delayed multipath component directly in the time-delay domain. Thus, a bi-static scan with wide-beam antennas identifies in the receiver output the direct and any delayed path as individual responses in the total

impulse response of the transmission path. This type of measurement was used to identify regions for multipath signals, followed by detailed level measurements where the transmitting antenna was changed to a narrow-beam parabolic dish. The specific results from this experiment were incorporated into computer model developments by MITLL. The reflection models are currently being used to facilitate computer simulation of MLS performance measurements.

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